OPTIMIZATION OF CONTAINER MANAGEMENT IN OCEAN CARRIER'S TRANSPORT NETWORKS

Vom Promotionsausschuss der
Technischen Universität Hamburg-Harburg
zur Erlangung des akademischen Grades
Doktor-Ingenieurin (Dr.-Ing.)

genehmigte Dissertation

von
Anna Varshavets

aus
Moskau

2017

Vorsitzender des Promotionsausschusses:
Prof. Dr.-Ing. Heike Flämig

1. Gutachter:
Prof. Dr.-Ing. Günther Pawellek

2. Gutachter:
Prof. Dr.-Ing. Carlos Jahn

Tag der mündlichen Prüfung:
13. Dezember 2017

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1 Introduction

1.1 Background and motivation

Container fleet and container ships have become the most important means of transport for international cargo traffic over the last 20 years. Ocean carriers, which are one of the main container suppliers, may offer a range of transport services not only in the maritime network but the inland regions as well. The integration of the inland leg of the intermodal door-to-door transportation service into the scope of ocean carrier's activities enables a better control of the container equipment. However, it also makes the container management process more challenging due to the complexity of the whole large-scale transport network.

One of the biggest problems that shipping companies are facing on the global level is the freight flow imbalance. Certain areas are predominantly exporting areas, whereas others are mainly importing areas. The imbalance is especially strong on the Far East-North Europe (1.9 to 1) and Far East-North America (1.6 to 1) trade route. As a result, around 20% of all maritime container transportation refers to the repositioning of empty boxes from the surplus areas to the areas where they are needed (Drewry Shipping Consultants, 2010). Even though empty containers are usually piggybacked on the regular liner services, fuel and handling cost is still incurred and added to the repositioning cost, which can account for around 27% of the total spending in container management (Song et al., 2005). The high cost of repositioning or other losses in the backhauls to Asia can be covered by certain surcharges to the freight rate in the headhauls. This, however, increases the price of imported goods and, thus, affects all the parties of the whole supply chain (Ng Ada, 2012). The accumulation of empty containers in the surplus areas also binds the storage capacities, which can impact the operation of the ports. To mitigate such effects of imbalanced container flows and improve empty container repositioning liner shipping companies search for solutions on strategic, managerial, logistic, IT and technological levels.

One of the ways to manage the imbalance is the short-term leasing of additional containers. There are, however, specific conditions and requirements from leasing companies that must be considered when making decisions on leasing. The review of the existing studies in container management optimization shows that the previous optimization models do not include all range of such constraints, whereas a more realistic representation of the short-term leasing option is needed.

When ocean carriers offer inland services for container haulage in the region, the problem of managing all empty regional movements arises. The total cost of regional empty container management can also represent a more significant number since it includes multiple cost components, e.g.: handling charges in terminals, rail or truck transportation cost between inland locations and ports, lift on/off charges at intermediate points, the cost of inland inter-depots repositioning, etc.

The problem of high inland repositioning cost is especially relevant for the North American intermodal transport system, which is characterized by the long-distance transportation. A significant share of North American customer clusters is located far away from the ports, in the middle of the country (Figure 1.1). Some clusters also generate a relatively low-volume export flow. As a result, in the situation of growing imbalances, growing fuel cost and high intermodal rates, the shipping companies are facing the problem of returning empty containers back to the ports. The attempts to pass the cost of empty container repositioning to the customers have often been not successful since the customers may always decide for the merchant's haulage if the price of the carrier's haulage is too high for them (Mongelluzzo, 2007a,b,c; Goh and Chan, 2016).

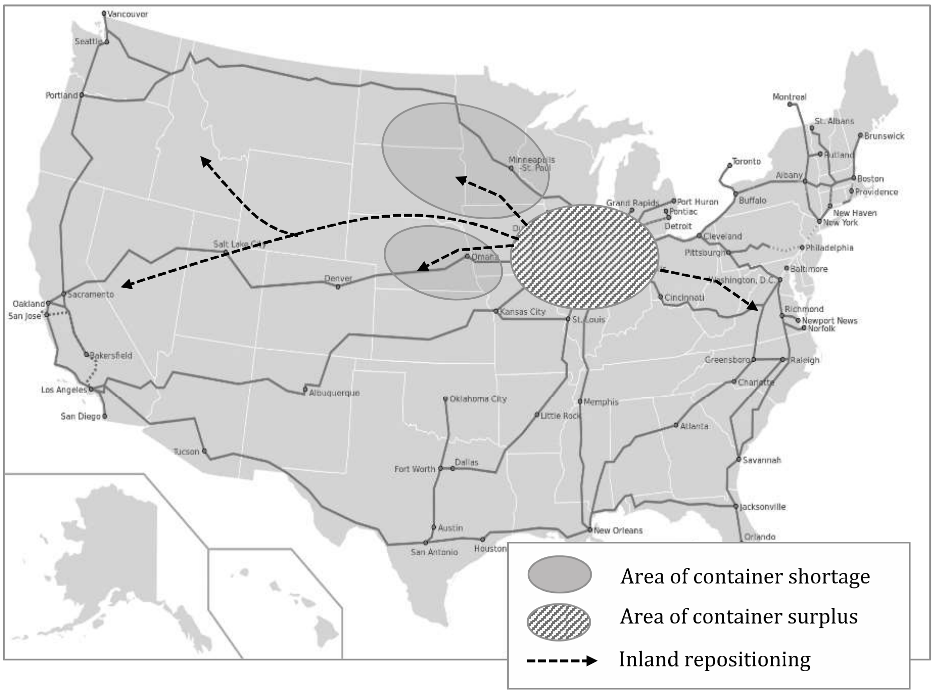


Figure 1.1:   U.S. intermodal inland service network

Another specific feature of the North American intermodal transport system is the existence of some hard-to-reach export locations that do not have sufficient number of empty ISO-containers available for export shipments (see Figure 1.1). The most affected areas are located in the western states of the U.S. Midwest region: e.g. Minnesota, Nebraska, Kansas, etc. In this case, empty boxes need to deviate from their main flow back to the port areas and be hauled to the place of their shortage. Such repositioning is typically charged with a higher cost. As a result, empty container movements diverted from the main backhaul flow delay the return of containers to the Asian region, which is associated with much higher profit from the shipping, and adds on to the total container management cost. Empty container movements, diverted from the main flow back to the ports, are typically associated with a higher cost. It must also be noted that, in the highly competitive inland transport market, the ocean carriers also face a challenge of fixing a viable price of back container-haulages that is greater than or equal to the short run marginal cost of accepting the export freight (Goh and Chan, 2016). The profit margin of export shipments on sea might also represent a very small or even no contribution to the round-trip container transport cost, inhibiting its recovery from the total empty container repositioning (Maersk Line, 2007; Stewart et al., 2013, p.6). In this situation, ocean carriers may prefer to avoid the opportunity of export shipments and move containers empty rather than reloaded with export cargo. Some ocean carriers (e.g. Maersk Line) have already started limiting their inland transport services. They typically restrict the turn-around time of their containers in the region, defining how far containers can go away from the ports (Mongelluzzo, 2007a,b,c; Maersk Line, 2007, 2016; Stewart et al., 2013, p. 5-6; Clott et al., 2015). Basing on the interviews with Maersk Line, the ocean carrier's inland service network undergoes a constant periodical review with a purpose of identifying the potentials for the optimization. As a result, it is reasonable to incorporate the option of inland service restriction into the strategic and tactical container management models.

Thus, the problem of empty container repositioning is highly relevant for both global and regional ocean carrier's transport networks. It represents a challenging issue that requires a holistic approach to the whole container management process and thus constitutes an important field of research.

1.2 Problem statement, scope and objectives

This thesis focuses on container management problem from the perspective of an ocean carrier that can offer both maritime and inland service networks for container shipping. Only the standard type containers are considered.

The primary goal of each carrier is to provide a needed number of empty containers at the least possible cost in order to satisfy the maximum amount of transport demand. Due to the trade imbalance, as well as seasonal fluctuations, certain ports always face a shortage of empty containers, while other ports generate a surplus of empty boxes. As a result, based on the information on how many loaded or empty containers are presented in a port at a time, and how many empty containers are needed in the inland region in case of inventory inadequacy, an ocean carrier makes a set of decisions for each port of the global shipping network. Ports with container shortage require a number of empty containers to be positioned in, added into the network through the long-term leasing agreements, or leased for a short period, round trip, or one-way trip. Ports with container surplus require a corresponding number of empty containers to be positioned out, temporally stored in depots, returned to the leasing companies or sold out of the network. A certain transport demand with a low-profit margin may also be rejected due to the insufficient container inventories, leasing restrictions, or inadequacy of the vessel capacity for total transportation (Goh and Chan, 2016; Graf von Westarp and Shinas, 2016). The option of transport demand rejection has been, however, rarely integrated into the optimization models, even though the derived demand for empty container repositioning in the network may make it profitable (for literature review see Table 2.2). Certain studies (Shintani et al., 2007; Song and Dong, 2013; Zhang, 2014) have been incorporating cargo rejection into the problem of shipping network design. At the same time, only a few studies (Brouer et al., 2011; Graf von Westarp and Schinas, 2016) consider the transport demand rejection in the actual container management.

Another option in container management that has been receiving little attention in the previous models is the short-term leasing. It must be noted that the short-term leasing option is characterized by a set of specific conditions. To prevent the excessive leasing in container shortage areas and the excessive return in container surplus areas, leasing companies use special drop-off and pick-up charges. In addition, they set a certain quota of containers that is allowed to be returned during a certain period of time (e.g. every month) in each port and in a region in total. This quota usually depends on the total volume of empty containers leased by a carrier. The leasing companies may also often set minimum lease duration for their equipment. All these special conditions of the short-term leasing must be correspondingly incorporated into container management models. However, the previous models (Shen and Khoong, 1995; Cheung and Chen, 1998; Chen and Zeng, 2009; Lu et al., 2010) include the long-term leasing decision primarily and treat leased containers as own inventory. The studies that address the short-term leasing (Li et al., 2004, 2007; Brouer et al., 2011, Ji et al., 2016) imply separate cost for different leasing options but do not impose any additional constraints for leasing. Neither do they treat leased and owned containers differently in the models. The exception is the study of Moon et al. (2010). However, even this model does not consider any relationship between the return quota and the number of leased containers at carrier's disposal. It also does not include the requirement of the minimum lease duration. As a result, an optimal organization of global empty container repositioning with consideration of the short-term leasing option and its specific conditions needs a more careful consideration.

Additionally to the global shipping services, an ocean carrier may offer a range of inland transport services as a part of the whole shipping chain. When a carrier overtakes the responsibility for the loaded shipments in the inland region, he also needs to take care of all resulting empty container moves:

- An empty trip from import location back to the port, to an inland depot for temporary storage, or to an export customer for the reuse;
- An empty trip from a depot/port to an export location; or
- The return of empty containers from inland depots back to the ports.

In addition, the specific case of the North American intermodal system includes some hard-to-reach rural areas in the region. When inland services to such areas require an excessive amount of time or are associated with a very high cost of empty container repositioning that cannot always be covered by the profit margin of shipments, the ocean carrier may prefer to limit its service network and reduce the number of inland locations served. In this case, a set of container-related decisions on a regional level will include:

- Which inland customer clusters to serve based on the profit obtained from the inland service network and considering the restriction of the ISO-container travel time in the region;
- How to organize all empty ISO-container trips that accompany loaded import/export movements;
- How to allocate and balance ISO-container inventories in an inland depot network resulting in a minimum container-related capital and operating cost.

It must be noted that when an ocean carrier no longer provides services to a certain customer cluster or an inland location, affected customers may still organize the shipments under their own responsibility as merchant's haulages or use the advantage of the transloading option. The latter implies the transportation of export cargo in domestic 53-ft containers to a port or intermodal terminal, where the contents are then reloaded into the ISO-containers for the further maritime shipping. The reverse order will represent an import movement. The movement of domestic 53-ft containers lies, however, outside of the scope of the current research work.

The problem of empty container management in the inland region has been addressed by multiple studies: e.g. Olivo et al., 2005, 2013; Di Francesco, 2006; Bandeira et al., 2009; Yun et al., 2012; Dang et al., 2012, 2013. At the same time, the described option of inland service restriction in North America, which allows an ocean carrier to decline certain demand for inland haulages on the Through Bill of Lading conditions, has not yet been considered in any optimization model. The option of cargo rejection has been addressed only in the global shipping (Shintani et al., 2007; Song and Dong, 2013; Zhang, 2014; Brouer et al., 2011; Graf von Westarp and Schinas, 2016). Neither is there any restriction on the total container turn-around time in the inland region, despite the clear tendency of the ocean carriers to speed up the cycle of their equipment in the North American inland region (Stewart et al., 2013, p. 6; Clott et al., 2015). Thus, the deployment and repositioning of empty container equipment in the ocean carrier's inland service network, considering an option of inland service restriction, need a more careful consideration.

Finally, having presented the challenges in the global and regional container management, it must be noted that the optimization of container management in the whole shipping network represents a great difficulty due to the network complexity and its large dimension. Empty repositioning problems, presented as network flow problems with integer variables, require a complex combinatorial optimization procedure. They are proven to be NP-hard (Zhang, 2014, p. 11). As a result, it may be computationally very difficult or even unrealistic to solve reasonable-size instances due to a large number of variables and constraints. For this reason, the existing optimization models for global container management are still formulated with certain simplifications: e.g. a single container type, simplified shipping network without consideration of port-specific characteristics, limited range of managerial decisions, etc. For the sake of computational tractability, the size of the problems is also often kept rather limited (Brouer et al., 2011). The application of different heuristic and metaheuristic approaches may help to reduce the computational time significantly while, at the same time, providing a good approximated solution to the problems. However, it is still impossible to create a comprehensive and computationally tractable model for global container management that reflects all realistic shipping conditions in a single model (Khakbaz and Bhattacharjya, 2014).

The inclusion of inland part into the maritime shipping network will increase the number of variables and constraints much more, making the optimization even more difficult. As a result, the scholars have been addressing the problem of empty container repositioning in global and regional container management separately. The other studies have been focusing only on specific regions or certain shipping routes (Song and Dong, 2008, 2011, 2013; Meng et al., 2012; Xu et al., 2015; Chao and Chen, 2015). Only very few studies discussed the interconnection and communication between managerial levels. An early study of Shen and Khong (1995) proposes to decompose the empty container repositioning into three inter-related planning problems (terminal/port planning, intra-regional, and inter-regional planning). The authors then discuss the communication between managerial divisions and present a heuristics that solves the empty container distribution on each level with the further perturbations to the planning decisions. The later studies (Erera et al., 2005; Meng et al., 2012; Dong and Song, 2012; Xu et al., 2015) demonstrate the importance of consideration of inland transportation leg or inland turn-around time in global container management. However, the authors can apply such formulation only for a simplified network or a single service route. Other scholars propose a decentralized or semi-centralized approach to the repositioning problem that gives a certain authority to the ports or regions (Di Francesco, 2007; Khakbaz and Bhattacharjya, 2014). However, no such model formulation has been proposed. As a result, a holistic view of container management, which takes into account the connection between global and regional networks, needs to be more carefully studied.

Based on presented above problems in container management and limitations of the previous optimization models, the main objectives of the thesis are as follows:

1) Propose a system of tactical models for optimization of maritime and inland container management considering the interconnection between networks through common averaged parameters incorporated in each model.

The chosen approach implies the decentralized process of tactical container management on global and regional levels. Incorporated in each model inland turn-around time of containers presents the main control parameter that enables the coherence and interrelation between networks.

2) Include more realistic representation of the short-term leasing in the global management.

Such representation implies a) modeling of leased and owned container flows separately; b) representing a drop-off restriction as a quota that varies monthly based on the volume of leased containers at carrier’s disposal; c) considering the requirement of minimum lease duration besides the drop-off and pick-up restrictions

3) Include an option of inland service limitation into the regional container management.

The proposed strategy allows ocean carriers to restrict their inland haulage services for certain customer clusters based on a cost of container management or time of container turnaround in the region.

1.3 Thesis structure

The thesis is organized as follows.

The next chapter provides a theoretical background for the development of the optimization models. It gives a more detailed description of the ocean carrier's operation, both in global and regional transport networks. Special attention is given to the inland service network in North America since the transportation process in this region is characterized by some features (e.g. transloading of containers in ports). These features will be reflected later in the model, proposed for the regional container management. At the same time, the main purpose of this chapter is to display the range of ocean carrier's decisions related to container management in different areas and planning levels and to discuss their complexity and interrelation. A more detailed presentation is given to the short-term leasing option, which has not been fully integrated into the existing optimization models. Finally, a review of existing mathematical models for global and regional container management is presented at the end of the chapter. Special attention is also given to the models that integrate both maritime and inland container movements. To the objectives of the thesis, the research gaps are discussed.

Chapter 3 describes the overall concept for container management optimization adopted in this thesis. The maritime and inland container movements are modeled separately. However, certain common parameters are integrated into both models. These parameters enable the interconnection between networks and make possible the integration of the models' results into one output. Further on, the chapter presents the detailed explanation of the Maritime and Inland Models. The aspects that must be considered for the integration of the models' results are discussed.

Chapter 4 presents the mathematical formulation for the proposed Maritime Model. It focuses on the global container management with a short-term leasing consideration. The model also involves the option of demand rejection in the case when the vessel capacity is not adequate for total container transportation. The assumptions needed for the mathematical formulation are given. In order to account for the dynamic decision process, a network flow is represented in a time-space network, and the model is given as a dynamic multi-commodity network flow problem that seeks to maximize the total profit obtained from the global container management. In order to incorporate the information about container flow in the inland region, the extension to the mathematical formulation of the Maritime Model is presented at the end.

Chapter 5 proposes the mathematical formulation of the Inland Model. It focuses on container management in an ocean carrier's inland service network. Only empty container movements are being optimized. It is assumed that the routing of loaded containers is done separately, and all transportation costs, times, as well as the rates, are given in the model. All assumptions needed for the mathematical formulation are explained. An inland container flow is also represented in a time-space network, and the model is given as a dynamic network flow problem that seeks to maximize the total profit from container management.

Chapter 6 provides the case study for the Maritime Model. It presents the global shipping network for the model implementation and explains all input data. Since the test instances typically present a large-scale problem, the possibility of network aggregation is described. The node consolidation enables the reduction of the size of the problem, and the speed-up of the computational solution. In order to study the leasing option in the different settings, the various scenarios are created. All instances are solved using Gurobi 6.5.0 as a solver, and results are discussed. A sensitivity analysis, conducted for certain scenarios, demonstrates the influence of different lease-related factors on container management decisions.

Chapter 7 presents the case study for the Inland Model. The case study is proposed for the U.S. Midwest region, which represents one of the main problem areas for empty container management. After the inland service network and the input data are explained, the model is solved using Gurobi 6.5.0 as a solver, and the results are discussed.

Finally, Chapter 8 presents the results of both models from a holistic perspective. An average container turn-around time in the inland region plays the main role as a connecting factor between maritime and inland transport networks. Thus, the chapter analyzes the container management decisions in both networks with different values of inland travel time.

2 Theoretical background to container management optimization

2.1 Liner shipping company's operations

2.1.1 Liner service network

The primary activity of the shipping companies is focused on the global port-to-port transport services, although in the past decades, more and more attention has been paid to the extension of services over the inland leg as well. Carriers typically establish regular weekly circular lines for container transportation, and then periodically adjust their characteristics in order to adapt to the market conditions and be able to satisfy the largest number of customers possible. The main service characteristics are vessel itinerary, frequency, capacity, and cruising speed, etc. On the internal operational level, the carrier builds a set of rules and policies, which aim to ensure that the proposed liner services are provided with an intended quality while operating in an efficient way (Crainic and Laporte, 1997).

The main focus of a shipping company's operation is on the dominant Transpacific, Transatlantic, and Europe–Asia trade lines. To serve these container flows, shipping lines offer end-to-end, pendulum, and round-the-world routes. The latter two provide a certain cost saving by merging separate end-to-end services together, enabling carriers to maximize their vessel deployment and slot utilization (Ting, 2007). In order to minimize the operating cost, certain shipping lines also start reducing the number of port calls and introducing the hub-and-spoke system into their network. The latter implies the shipping only between major ports of the regions with further transportation between regional/local ports using feeders. Despite the existence of a vast number of other route patterns, which makes liner service network fairly complex, the shipping of containers is almost exclusively done using the pendulum services. It is designed as a continuous loop, representing a certain sequence of port calls along at least two maritime ranges (Rodrigue et al., 2013). Transshipment of loaded containers from one service to another one is not allowed.

Each group of container liner services has its typical vessel capacity. The overall tendency is towards the deployment of larger units, which allows ocean carriers to benefit from economies of scale. However, a certain trade-off must be made between volume and frequency since the smaller vessels enable meeting the customer demand with higher frequencies and lower transit times.

The market condition greatly influences the freight rates charged for container transportation. It must also be noted that historically ocean carriers have been focusing on the headhaul from strong exporting areas (e.g. Asia). The cost of empty container repositioning back to these regions, which arises from the global freight flow imbalance, is typically built into the headhaul price. At the same time, the shipping direction with a weaker container flow is offered at a cheaper rate to attract more customers and get a higher contribution to the round-trip operating cost. As a result, the imbalance of east- and westbound freight rates on specific routes can reach over 50% (Figure 2.1). In this situation, certain ocean carriers choose to focus on the services for markets that have some prospect for a balanced flow of imports and exports (Stewart et al., 2013, p. 7).

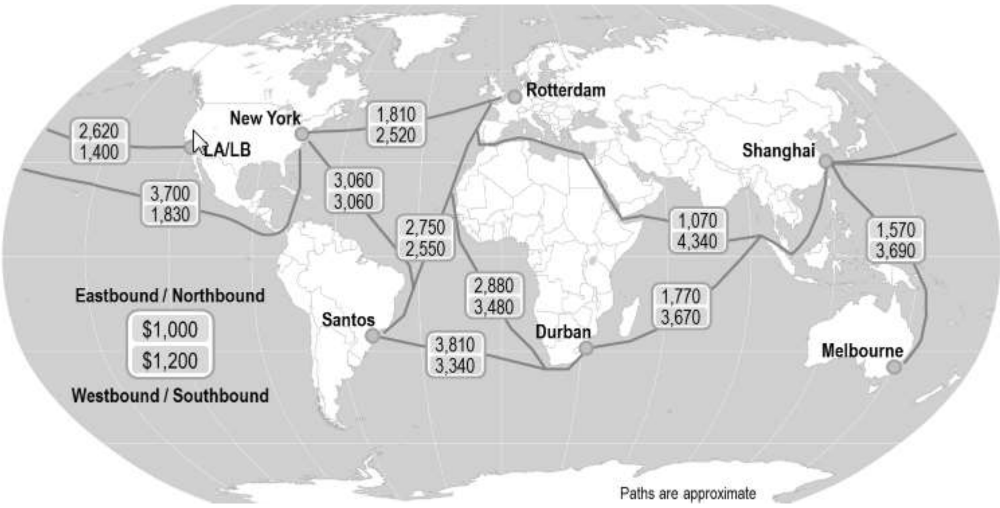


Figure 2.1: Shipping rates for 40-ft container on head- and backhaul of the main shipping routes (Rodrigue et al., 2013)

Though additional surcharges to the freight rate can ease the burden of empty container repositioning to a certain extent, the problems caused by imbalanced freight flows still represent one of the most relevant issues in the liner shipping. In the situation of raising overcapacity, high bunker costs, and falling freight rates among others, the organization of efficient container logistics can determine the success of ocean carrier's operation. Many shipping companies continue to improve their position in the market by offering door-to-door services, which enable a tighter control over their container fleet, resulting in its more efficient management. The key features and challenges of the ocean carrier's inland services are described in the following section.

2.1.2 Inland service network

Transportation process organized by the shipping company on the inland leg of the global shipment is called Carrier's Haulage. Ocean carriers typically undertake the organization of inland haulages mainly to rail yards or the other main inland facilities, although the transport service to a customer's site is also possible. As the shipping companies normally do not own transport equipment for regional container movement, they subcontract transport services from rail, barge, and trucking companies. The whole shipping chain from a foreign port/shipper's site to an inland location/consignee's site is then covered under the single Through Bill of Lading, issued by the ocean carrier, and the whole process is defined as Multimodal Transport. The full responsibility for the transportation with all its emerging costs lies exclusively on the liner shipping company. In order to serve customers with empty containers, ocean carriers also deploy a number of empty container depots in the region. As a result, the ocean carrier's inland service network comprises a network of ports, container depots, and customer locations, connected through a range of transportation routes.

The transport process on the inland leg of the global shipment can be organized using different schemes, where the main elements are predominantly rail and truck. In the North American intermodal transport network, this process can have even more options due to the existence of transloading possibilities. The comprehensive review can be found in Xu (1999). The simplified representation of transport options for import shipment is summarized in Figure 2.2. The export shipment will take the same process but in reverse order.

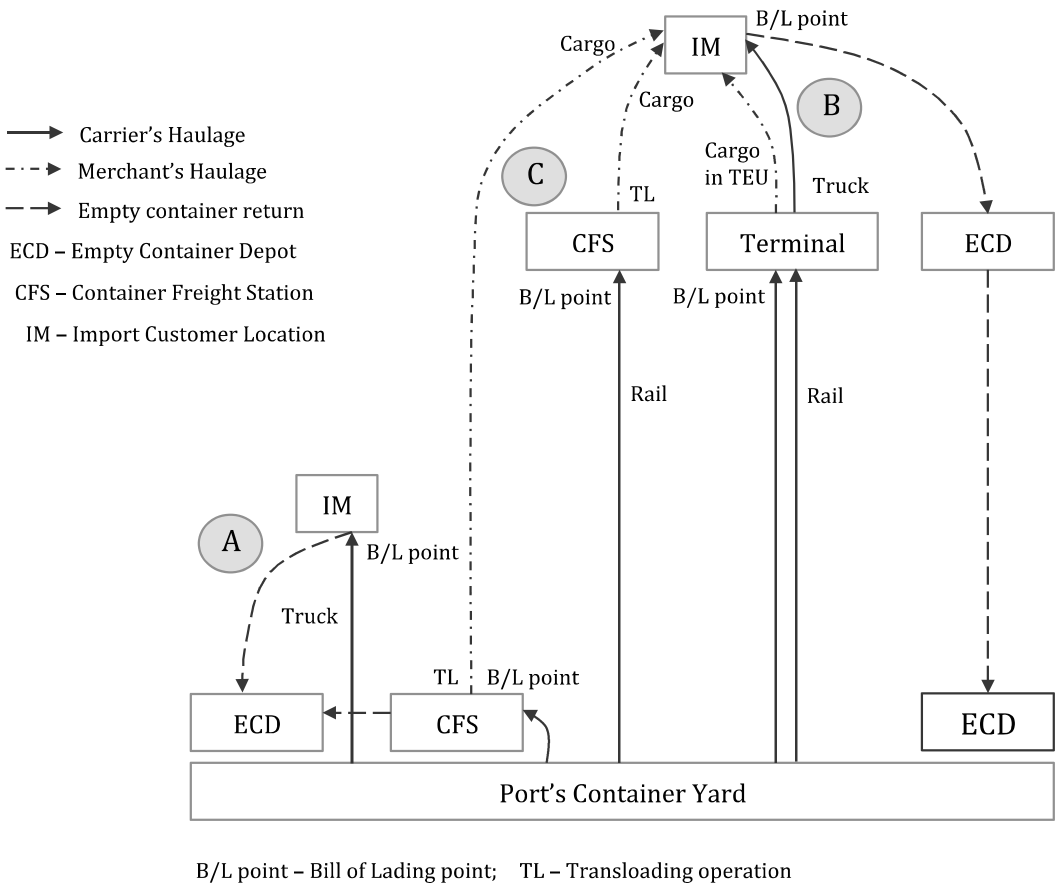


Figure 2.2: Inland haulages for import shipment and ocean carrier's services

When import containers arrive at the port, they are designated to a container yard, where they wait until the pick-up by the truck for the further delivery (typically within a port's region) or moved to the rail siding for the on-going rail transportation. Necessary operations like inspection and customs clearance can also be done there. In the case of Less-than-Container-Load[1] shipment, containers are being sent to the container freight station for stripping and on-going transportation of separate cargo to the customer. In this case (see case A in Figure 2.2) containers stay in the proximity of the port, circling between depots and customers.

In the situation of growing international trade, limited port capacities, and port congestions, port terminals start extending their gates by establishing inland terminals or inland container depots that perform the same functions as the ports. In this way, containers can be transported between ports and inland depots under customs bond and the ocean carrier's responsibility. This transportation is typically performed by rail, using the benefits of economies of scale (see case B in Figure 2.2). An extensive rail delivery system is especially of fundamental importance to the North American region, which is characterized by long-distance transportation on main trade corridors between maritime gateways along the West and East Coast and far away inland points (see Figure 1.1). Thus, for instance, half of the cargo handled in LA/LB area, which accounts for about 70% of the American West Coast container traffic, goes to Chicago (3-4 days) and New York (5-6 days) (Rodrigue, 2013, 2012). Then containers are drayed by truck from the intermodal terminals to the final destinations. After the import shipment is accomplished, empty containers can be returned to the empty container depot near the intermodal terminal for temporary storage before assignment to the next export shipment or repositioned back to the port area. The main challenge here is the cost of all empty container movements.

Inland regions are often characterized by economic specialization and, thus, repositioning of empty container surpluses from importing areas to manufacturing or rural exporting areas is not unusual (Rodrigue, 2007). The problem is, however, complicated by several other aspects in the U.S. Midwest region (Stewart et al., 2013):

- Hard-to-reach location of certain rural shippers, which increases the total turn-around time of marine containers;
- Low-revenue export shipment of agricultural products;
- Low-volume export flow and high maintenance cost of empty container pools in the rural areas;
- Weight imbalance between export and import flows (heavy grains vs. light import goods), which causes difficulty maximizing container asset utilization due to the weight limits for trains and vessels;
- High rail rates for empty container repositioning on secondary rail lines, which deviate from the main direction back to the port areas, etc.

[1] Less than Container Load (LCL) – consolidated shipments of multiple customers in one container.

It must be noted that the cost of empty container movements is typically incorporated into the carrier's haulage tariffs. However, the price setting is characterized by the pressure from the competitors and inland transport operators. As a result, it may not always be possible to pass the full empty container repositioning cost to the customers (Mongelluzzo, 2007a,b,c)

Finally, the ocean carrier can also offer container delivery under the Through Bill of Lading condition only to a specific intermodal terminal (Bill of Lading point). The customer then will need to organize the truck drayage by it own or move the container to the transloading facility, where the content of containers is reloaded to the domestic container or trailer, and sent to the customer's final destination (see case C in Figure 2.2). In this case, the distance traveled by the marine container is limited, and the total turn-around of equipment in the region is being sped up.

Based on the shipment type, an ocean carrier sets certain inland rates, which are then integrated into the total door-to-door shipping price. If the carrier's haulage tariffs are above the open market price, merchant's haulage becomes the choice for the customer (Di Francesco, 2007). In this situation, full responsibility for marine container lies on the client, who needs to organize the inland delivery on its own and return the carrier's equipment to a predetermined point of container interchange. The customer is typically given a limited amount of time to bring the container back without being charged for container usage.

Although selling the carrier's haulage for inland container movement increases the visibility over the container fleet in the region, it also introduces the complexity and additional financial effort for the shipping company in organizing the regional container managements. The profit margin of the sea transportation normally covers both global empty repositioning and repositioning in the port hinterland. However, when the profit margins of the sea transportation leg are low, and the revenue of the head-hauling cargo on the land leg is too small to cover the round-trip door-to-door costs, it can be reasonable to limit the door-to-door service network to avoid the cost of returning empty containers to marine terminals. As a result, in order to address the challenges in global and regional container management, ocean carriers are constantly reviewing their services with a purpose of periodical adjustments to the demand changes, as well as finding potentials for optimization.

The following section aims to provide a review of a complex set of decisions related to container transportation and container fleet management.

2.2 Complexity of container management decisions

2.2.1 Planning levels and scope of decisions related to empty container repositioning

Container management is a complex process, which involves different levels of decisions related to vehicles, facilities, and activity areas. It is closely connected to how an ocean carrier organizes its operation on a global and regional scale. Decisions on, for example, an ocean carrier's service network design or inland depot location can improve the flow of the empty equipment in the transport network. As a result, such strategic and tactical decisions are setting the goals and limits for actual day-to-day operations on empty container movements. The overview of all possible decisions related to empty container repositioning is presented for a different planning level and a class of a problem in Figure 2.3.

Strategic decisions are long-term, complex decisions made at the highest managerial level, which will determine general policies and strategies of the shipping company. These decisions also typically involve large capital investments over the long time horizon. According to Crainic and Laporte (1997) and the review performed by Braekers (2012), the main group of the problems addressed on this level refers to the design of the physical network by selecting facility locations and facility size, acquiring resources, and defining broad service policies.

Tactical decisions are medium term planning decisions, following on from strategic guidelines and policies. The main goal of tactical planning is to ensure an efficient and rational allocation and utilization of existing recourses in the global and regional transport network in order to achieve the economic goals of the company and a certain of customer service (Crainic, 2000). As a result, most decisions on this level refer to the service network design (Crainic and Laporte, 1997). Since the need to move empty containers or vehicles characterizes any freight transportation system, the problem of empty repositioning is closely related to the design of transport services. Empty container balancing is, however, typically treated separately, although there have been attempts to address both problems on the global level simultaneously (Shintani et al., 2007; Imai et al., 2009; Meng and Wang, 2011).

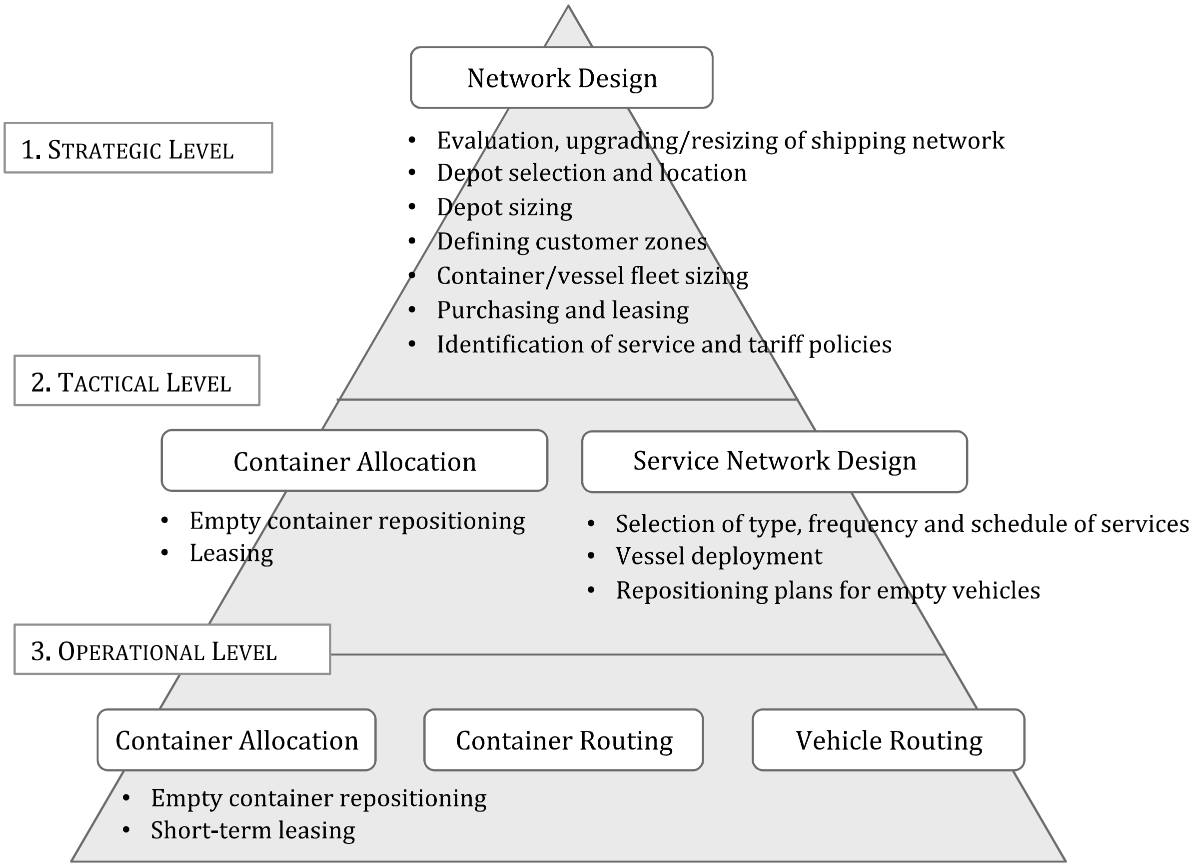


Figure 2.3: Overview of decisions related to empty container repositioning (adapted from Braekers (2012), p. 17)

It must be noted that the tactical planning does not aim to determine an actual plan for empty repositioning, but rather defines a magnitude of the flows, which will later form the framework for real-time operational decisions (Crainic et al., 1993b). It also does not require detailed day-to-day information about container status in the network but allows the aggregation of data. The leasing option is incorporated into decision-making process as a strategy to avoid the container shortage due to seasonal demand fluctuations or other uncertainties and is planned normally for long- to mid-term arrangements (differences between leasing types are discussed later in this section). However, the short-term leasing option can also be included in the planning with a purpose of developing the guidelines and policies for the operational level.

Operational decisions comprise day-to-day choices made by regional and local offices of a shipping company in a highly dynamic and often uncertain environment. The main groups of decisions refer to container allocation and container/vehicle routing.

As opposed to tactical planning, operational decisions on empty container allocation are planned for implementation in a real-time environment. Its main goal is the distribution of empty containers between consignees, shippers, inland depots, and port terminals with a purpose of meeting the present and forecasted customer demand at the lowest operational cost. The detailed representation of all elements in the transport process, as well as transport activities, is essential in such planning since the decisions refer to very specific operations: e.g. container trucking, handling, inspection, cleaning, repair, allocation in a terminal, placement on a vessel, etc. The short-term leasing decisions are incorporated into container allocation to satisfy an acute unpredictable demand for empty equipment. Routing decisions provide both the best container itinerary and the best route for the vehicle in the given intermodal transport network.

Since the focus of the maritime part of the Model System is the problem of empty container repositioning with consideration of short-term leasing possibility, the specific conditions and requirements of leasing arrangements are studied in more detail. Table 2.1 summarizes their main characteristics basing on conducted interviews with leasing companies and existing studies of Muller (1995), Theofanis and Boile (2009), Buss Capital (2011, 2013), DRSB (2015), Advani (2015).

Concerning the term of the arrangement, the types of leasing fall into 2 main categories: long-term lease and short-term lease. The latter can be further classified as Service Lease/Master Lease, and Spot Lease.

Long-term operating lease: Long-term lease is typically used to add capacity to existing services and to support ocean carriers in their container fleet expansion, replacement, and renewal requirements. The contractual term ranges from 3 to 8 years with an average term of approximately 5 years. During that period, an ocean carrier is responsible for all aspects of container maintenance, repair, and repositioning. After the end of the lease term, containers often stay on hire at the contractual per diem rate for the additional 6 to 18 months due to specific fleet requirements of a lessee (DBRS, 2015). Ocean carriers typically incline to the long-term lease arrangements because of ability to fully integrate the acquired equipment into their fleet, which enables a more efficient container management.

Table 2.1: Characteristics of container leasing arrangements

	Short-term lease		Long-term lease
	Service Lease/Master Lease	Spot Lease	
Lease term	Contract for 1 year or more	One-way/round trip	3-8 years, 5 on average
On-hire time	3 months or more	Lease term	Lease term + 1 year beyond term
On-hire volume	Variable number (min/max)	One-time, small, fixed number	One-time, large number (min 100)
Pick-up	When needed, at worldwide locations	Agreed location	Limited agreed locations, within 3-6 month period
Drop-off	Monthly quotas depending on on-hire volume	Agreed location	End of term, at mutually agreed locations
Per diem rate	High (~20% higher than long-term lease)*	High and very volatile	Low, depending on the term
Billing	End of month with possible credit of 30-60 days	End of lease	In advance monthly during the term
Other issues	Minimum commitment clause for lessee	--	Lessee's full responsibility for containers

* Buss Capital, 2013

Short-term leases: Short-term lease, on the contrary, offers an ocean carrier the flexibility in the situation of fluctuating demand, which comes with a higher per diem rate compared to the long-term arrangements, and enables avoiding the long-term binding of capital. The short-term lease arrangements under Service Lease agreement are typically made for 1 year and more, for a certain range of containers (maximum and minimum). During this term, equipment can be picked up, when needed, at any location from the predefined list, and later dropped off, subject to some contractual limitations. In order to prevent an excessive leased number in container shortage areas and excessive return in container surplus areas, the leasing companies use not only specific pick-up/drop-off charges but also set total return limits for a month and each specific location. Drop-off quotas are usually discussed with an ocean carrier. As a result, the value of these quotas depends on the carrier's negotiating skills and the volume that is being leased. Because containers can be returned during the term of a lease, lease term does not dictate expected on-hire time for the equipment, although leasing companies can require minimally allowed on-hire duration.

A variant of a short-term lease is a spot lease, which is used when the ocean carrier urgently needs containers for a very short period (e.g. a one-way trip or a round trip). The number of containers leased is fixed and normally very small with a pick-up and drop-off at specific predefined locations. The per diem rate is high and very volatile as a result of market conditions. Moreover, the leasing companies try to avoid having a significant share of their equipment on the spot market due to high risks of having a large volume of idle equipment during low demand periods.

In general, a lease agreement (documentation) consists of 2 basic elements (DRBS, 2015):

- Master lease agreement, which outlines general rights and obligations of a lessor and a lessee;
- Multiple lease addenda, which specify per diem rate, term duration, drop-off schedule for specific leasing transactions under the master lease.

Master lease agreement often offers an ocean carrier a minimum commitment clause possible. For example, the leasing company can take full responsible for the management of the container fleet, such as repositioning, maintenance, and repair. In the accounting system, debits and credits can be including depending on the condition of equipment at the time of interchange. As a result, the short-term leasing option can represent an attractive alternative to empty container repositioning in certain cases.

2.2.2 Interconnection between decisions

The classification of decisions in the previous section (Figure 2.3) demonstrated their clear hierarchical structure: physical network provides the framework for setting the configuration of global and inland transport service networks, where the actual real-time transport operations with loaded and empty containers take place. At the same time, when making strategic and tactical decisions, the information regarding container transportation processes from the lower operational level is essential for the planning. The interconnection between the major managerial decisions on different levels is further demonstrated in Figure 2.4, where bold straight lines ensure the hierarchical relation and dotted lines display the interconnection as well as main influencing aspects. Only main issues related to container management are presented.

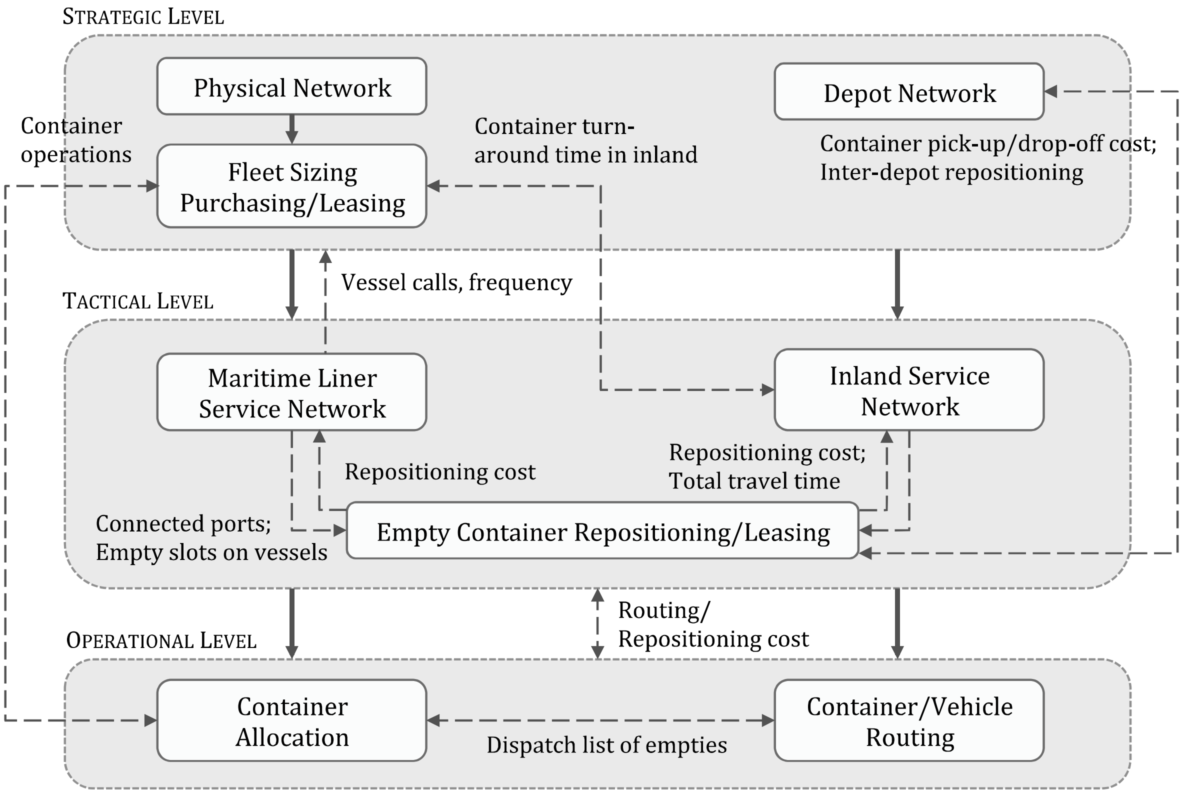


Figure 2.4: Interconnection between main decisions related to container management

Complexity of strategic decisions: Container fleet sizing is one of the most important aspects of container transportation system that affects the ocean carrier's operation. It is an aim of the shipping companies to minimize capital and operational expenses related to owning and using their equipment while satisfying all customer demand for shipping. In order to determine an optimal size of the fleet, multiple factors must be considered: e.g. number of container vessels, their capacity, the frequency of calls on a route, number of routes, etc. As a result, the configuration of the global shipping network has a direct influence on the fleet sizing decisions. At the same time, a set of ocean carrier's inland transport services must also be considered. The composition of inland service network defines how long containers can stay in the region, which eventually affects the size of the container fleet (Atkins, 1983; Dong and Song, 2009). The increased container turn-around time in the region has a potential to provide additional revenue from the inland container movements, but it also necessitates the increase in container fleet size, which leads to the higher capital and operational costs, additional expenses for storage space, maintenance, drayage, etc. As a result, to keep down unnecessary container-related costs, many carriers are trying to restrict how far their equipment can go into the inland, while others cut down the number of inland locations that they can serve.

Container fleet sizing is also closely related to the operational decisions on container movement. The reduction in the size of container fleet leads to certain savings. However, it also increases the need for empty container repositioning, the cost of container leasing in case of unpredictable shortage, and even the risk of losing the customer as a result of container unavailability (Braekers, 2012, p. 36). Despite this relations, there are still very few attempts to combine strategic decisions on container fleet sizing with operational decisions on container allocation into single planning tool due to the large level of complexity (Kochel et al. 2003).

Another group of strategic decisions, which is closely related to empty container balancing, is the depot location planning. An optimal selection and location of inland container depots enable the improvement of the collection and supply of empty containers from/to customers by minimizing the total transportation cost. Moreover, the consolidated empty container repositioning between depots on longer distances can also enable the cost reduction compared to single empty container movements between depots and customers (Crainic et al., 1993a).

Complexity of tactical decisions: As was already stated before, the main group of tactical decisions provides the physical setting and the tactical policies for container shipping on the global as well as regional level. Thus, these decisions directly affect ocean carrier's operation, resulting in a certain operating cost and a service quality. The construction of optimal routes and vessel calling schedules depends on many factors, such as expected customer demand, seasonal cargo fluctuations, market requirements, company's service policies, the need of empty container balancing, etc. The latter aspect is especially important since it represents a significant repositioning cost, which can be affected by the network design, vessel capacity, and availability of empty slots on vessels. In certain cases, it might be even more reasonable to forgo unprofitable cargo demand whose generated revenue cannot offset the associated repositioning cost (Shintani et al., 2007). As a result, an explicit consideration of empty container flows in decisions on service network design can enable a more efficient container allocation plan.

While the shipping company is directly engaged in the design of physical routes on the maritime level, the regional container transportation is being planned using already existing inland transport networks provided by other parties. However, if the shipping company offers the carrier's haulage for container movement in the region, it still needs to build its service network regarding consolidation and routing of container flows, the choice of transportation mode, intermediate stops, and intermodal terminals for handling operations, etc. The cost of future empty container repositioning in the region can also affect the decisions on which customers can be provided with services, and which customer location will need to use alternative options (e.g. cargo transloading in the closest intermodal facility, routing through another port, etc.). In the situation of existing carrier's overcapacity, increasing fuel costs, and increasing rail rates in the North American intermodal network, certain ocean carriers choose to resort to simplification of their inland service network in the region (Magnusson and Wienberg, 2012; Mongelluzzo, 2007a,b,c).

The issues in the interconnection of empty container repositioning and service network design reflect only a part of the complexity of the tactical decisions related to container management. The other aspects affecting the inland service network refer to: maintenance cost for container pools in the region; increased turn-around time of containers when serving some hard-to-reach customer locations; weight imbalance for import and export shipments; weight regulations for heavy trucks; road and terminal congestions, etc. (Stewart et al, 2013).

Complexity of operational decisions: Having provided a specific configuration of the transport service network with fixed operating rules and policies, the day-to-day decisions on container and vehicle movements can be made. Traditionally, due to high computational cost, container allocation and vehicle routing decisions are made separately: the first provides the dispatch list of empty containers, and the second determines the most cost-efficient itinerary of the vehicle comprised of loaded and empty movements (Crainic et al., 1993b). The simultaneous decision-making on both problems is complicated by numerous factors: involvement of different transport modes, the existence of multiple container types and sizes, consideration of fixed time windows for deliveries, etc. Moreover, a routing decision must not only provide the best itinerary for containers, but it also must match the requested container movement to a multi-stop "circuit" route of a vehicle. Despite such complexity, some efforts have been made in recent years to integrate container allocation and vehicle routing decisions into a single planning tool. Although a lot of simplifications are normally made in order to keep the problem computationally tractable, e.g.: consideration of a single container type, simplified transport network, limited range of possible container movements, exclusion of time constraints on a delivery, etc. (Zhang et al., 2009; Zhang et al., 2010; Bandeira et al., 2009; Huth and Mattfeld, 2009; Braekers et al., 2013).

It must also be noted that empty container repositioning in the global shipping network normally does not require routing decisions, as empty containers are simply piggybacked on the regular liner services using available vessel capacity.

Thus, having identified the complexity and intricate relationships among various decisions on different levels and in different activity areas, it must be noted that addressing all the aspects of container transportation process in a single planning tool is not realistic. As a result, specific issues at a specific level of decision-making are being addressed separately (particularly, the issues on global and regional scales). The complexity of maritime and inland transport networks itself prevents simultaneous planning of maritime and inland container management. However, consideration of interconnection between these managerial levels can enable a higher efficiency of the whole system and thus must be studied more carefully.

2.3 Mathematical models in the literature

2.3.1 Mathematical models for global container management

Extensive attention in the literature has been devoted to container management problems. A significant group of studies has been carried out concerning empty container repositioning, as it is an essential part of many freight transportation problems.

The literature review shows a significant amount of deterministic models. They treat the problem of empty container management from operational and tactical perspectives, in the setting of alternative options of leasing, container purchasing, demand rejection, etc. Incorporation of all possible options of container management into one model and solving it seems to be unrealistic. The literature review shows that no such model exists so far. The overview is summarized in Table 2.2.

A significant portion of studies is focused on container management as a network flow problem. Such models are typically presented for multi-period dynamic networks with a rolling horizon approach. The first model is proposed by Shen and Khoong (1995). They also incorporate leasing decisions. However, all containers are modeled as a single flow in the network. Neither technical aspects nor experimental results are discussed in the paper. Cheung and Chen (1998) later extend the dynamic network with uncertainty factors and present a two-stage stochastic network model, which is solved with a stochastic quasi-gradient method and a stochastic hybrid approximation procedure. The model treats leased containers the same as carrier's owned containers.

The more recent studies are dealing with container management problem primarily in a deterministic network. Feng and Chang (2008) propose a deterministic empty container repositioning model with a focus on an intra-Asia region. The repositioning decisions are made for different container types basing on a safety stock management. No leasing decisions are involved. However, a slot purchasing option is proposed. Kim (2004) presents a deterministic model that focuses only on a scheduling plan for leasing and container purchasing decisions. Both long-term and short-term leasing options are considered. The short-term leasing does not, however, include all possible requirements. Moreover, these decisions are modeled apart from repositioning. Neither solution nor experimental results are presented. The recent study of Moon et al. (2010) incorporates empty container repositioning, leasing, and container purchasing decisions in a single deterministic model.

Table 2.2: Overview of global container management models (based on the approach in Braeker (2012), p. 30)

Model class	Author(s)	Approach			Modeling elements					
		Deterministic	Stochastic	Simulation	Demand rejection	Loaded & empty flow	Long-term leasing	Short-term leasing	Container purchasing	Slot purchasing
Empty container repositioning (ECR)	Shen and Khoong (1995)	•					•			
	Cheung and Chen (1998)		•				•			
	Feng and Chang (2008)	•								•
	Kim (2004)	•			•		•	•	•	
	Moon et al. (2010)	•					•	•	•	
	Chao and Yun (2012)	•								
	Chao and Chen (2015)	•								
	Ji et al. (2016)	•					•	•		
	Zheng et al. (2015)	•								
	Erera et al. (2005)	•				•				
	Brouer et al. (2011)	•			•	•	•	•		
	Bell et al. (2011)	•				•				
	Bell et al. (2013)	•				•				
	Song and Dong (2012)	•				•				
	Yin (2012)	•	•							
	Di Francesco et al. (2009)	•	•							
	Lai (2012)		•							
	Long et al. (2012)		•							
	Long et al (2015)		•							
	Graf von Westarp and Schinas (2016)		•		•	•				
	Lai et al. (1995)			•						
	Lam et al. (2005)			•						
Service network design incl. ECR	Shintani et al. (2007)	•			•	•				
	Imai et al. (2009)	•				•				
	Chen and Zeng (2009)	•				•	•			
	Meng and Wang (2011)	•				•				
	Huang et al. (2015)	•				•				
Ship deployment incl. ECR	Liu et al. (2011)	•				•				
	Wang (2013)	•				•				
	Song and Dong (2013)	•				•				
	Akyüz and Lee (2016)	•				•				
Slot allocation problem	Song et al. (2007)	•				•				
	Lu et al (2010)	•				•	•			
	Chang et al. (2015)	•				•				
Inventory problem	Li et al. (2004)		•					•		
	Li et al. (2007)		•					•		
	Song and Dong (2008)		•							
	Song and Dong (2011)	•	•		•	•				
	Lee et al. (2011)		•	•						
	Lee et al. (2012)		•	•						
	Song and Zhang (2009)		•							
	Zhang (2014)		•		•					

It also includes a short-term leasing option and treats owned and leased containers in the network separately. The requirement of minimum lease duration or the restriction of drop-off quotas for to container volumes available at carrier's disposal is not considered. The model is solved using mixed integer programming, genetic algorithms (GA), and hybrid GA to reduce computational time.

The further studies investigate specific conditions in empty container repositioning. Thus, for example, Chao and Yun (2012) present an optimization multi-commodity network flow model for empty container repositioning within Asian region considering the specific hierarchical structure of that shipping network. The network comprises the routes of large container vessels, carrier's owned feeder vessels as well as common feeder vessels of other carriers. Chao and Chen (2015) present an operational optimization model that aims to minimize the repositioning cost of empty reefer containers within Asian ports. The research work of Ji et al. (2016) addresses the empty container reposition problem on a cyclic voyage route of the short sea shipping. The authors incorporate the strategy of mutual renting of empty containers among the partnering companies in the short sea liner alliance. However, no specific requirements or conditions are imposed for renting option. Zheng et al. (2015) address an option of sharing of empty containers among liner carriers. The authors present a two-stage optimization method that, on the first stage, seeks to find an optimal repositioning plan for all related liner carriers, and on the second stage, determines the optimal container exchange between the carriers.

The optimization of both empty and loaded container flows is addressed in Erera et al. (2005). The authors present a deterministic network flow model that aims to minimize the total management cost of tank containers in the global network. No leasing decisions are considered. Another model that optimizes both empty and loaded container flows is proposed by Brouer et al. (2011). The authors present a model for cargo allocation on routes taking into account empty container repositioning. The model is formulated as a deterministic multi-commodity flow problem that maximizes the total profit from shipping network. It allows the load rejection and includes a leasing option. Leased containers are, however, treated the same as carrier's owned inventory. No specific leasing conditions are incorporated. The routing of loaded and empty containers in the service network is also addressed in Bell et al. (2011, 2013). The authors present an LP model that assigns both full and empty containers to the shipping services based on the minimum sailing time as well as container dwell time in the ports. Later, the model is modified to minimize the expected cost rather than expected travel time. The problem of empty and loaded container routing with an option of container transshipment between several services is modeled in Song and Dong (2012). Yin (2012) also includes transshipment activities into empty container repositioning problem. Later, the author extends the deterministic formulation of the model into the stochastic problem with a large number of scenarios of uncertainty.

The problem of empty container repositioning with stochastic nature of the shipping process is also addressed by several other studies. Di Francesco et al. (2009) propose a deterministic model for optimization of empty container repositioning and then generate a set of scenarios in order to reflect the uncertain nature of specific parameters. Long-term leased containers are modeled as carrier's owned inventory. Lai (2012) proposes a similar approach of multi-scenario optimization, where scenarios are linked together by "none-anticipativity" conditions. Such connection enforces identical decisions over all scenarios. Long et al. (2012, 2015) investigate an empty container repositioning problem with uncertainties by using a sample average approximation method.

Graf von Westarp and Schinas (2016) propose another approach to addressing the uncertain nature of costs and freight rates. The authors present an LP model for container repositioning problem that aims to maximize the total profit from container management. Then they extend the model to the fuzzy LP formulation treating the profit as an uncertain fuzzy variable. No leasing decisions are included.

Only a very small group of research works (Lai et al., 1995; Lam et al., 2005) addresses the stochastic issues in empty container repositioning using simulation. Lai et al. (1995) employ the heuristic search to identify an effective combination of policies referring to safety stock level and container allocation at ports. The number of short-term leased containers is introduced as means to avoid the shortage. Lam et al. (2005) use an approximate dynamic programming approach to derive effective operational strategies for empty container relocation in a simple two-port two voyages system.

Another approach to empty container repositioning is to address the problem in a broader scope. Thus, for example, a group of studies (Shintani et al., 2007; Imai et al., 2009; Chen and Zeng, 2009; Meng and Wang, 2011) tackles empty repositioning problem as a part of strategic shipping network design. In this case, the main focus is to select a set of ports and determine a sequence of ship calling taking into account the size of the vessels, and the volume of containers to be shipped. As a result, loaded and empty container flows are being optimized together. Imai et al. (2009), and Meng and Wang (2011) extend the problem formulation by introducing the Hub-and-Spoke system. Huang et al. (2015) introduce an option of container transshipment between different service routes into their problem formulation. This group of the models is typically formulated as a mixed-integer or integer programming problem that seeks to maximize the total profit from vessel operations (Shintani et al., 2007; Chen and Zeng, 2010) or to minimize the total cost of service network (Imai et al., 2009; Meng and Wang, 2011; Huang et al. 2015). Chen and Zeng (2010) introduce a non-linear function of shipping cost into the profit function of the model and solve it with a method based on a bi-level generic algorithm. The authors also choose an optimal configuration of own and leased (long- and short-term) equipment, while determining the quantities of containers loaded on a vessel.

Liu et al. (2011) extends the optimization model further and combines ship-repositioning decisions with empty container repositioning. Wang (2013) includes both empty container repositioning and slot-purchasing decisions for different container types. The author demonstrates that these decisions have a large influence on the tactical planning of fleet deployment. The study of Song and Dong (2013) goes even further. The authors present a methodology for designing a single liner long-haul service route, including ship deployment and empty container repositioning. The model is solved in three stages. At first, the route structure solution is narrowed down to a certain target set. Secondly, an efficient empty-container-repositioning algorithm is applied with the aim of minimizing the empty container lifts at ports and the number of containers transported by sea. Finally, the number of ships deployed and their sailing speed are optimized. The latest work of Akyüz and Lee (2016) approaches the problem of ship deployment and cargo routing decisions with repositioning of empty containers under certain transit time requirements.

Other group of studies (Song et al., 2007; Lu et al., 2010; Chang et al., 2015) focuses on the slot allocation problem. It determines how many slots vessels should keep for ports of call to accommodate loaded and empty containers of different types with a purpose to maximize the profit from round-trip ship voyages. In this context, the authors incorporate decisions on empty container allocation on routes. Song et al. (2007) include both carrier's own and long-term leased equipment of four main types. The model's formulation is based on the integer programming. Such models, however, do not support decisions on empty container distribution in the shipping network. The later work of Chang et al. (2015) proposes an LP formulation with a bi-level structure. The upper level optimizes the slot allocation plan for the loaded containers with a purpose of profit maximization; whereas the lower lever aims to minimize the transportation costs for empty container repositioning.

Finally, another portion of research works uses inventory theory to address empty container repositioning problem. Thus, for example, Li et al. (2004) propose a non-standard inventory problem to determine an optimal policy for strategic repositioning-in and repositioning-out decisions for a single port. Later on, Li et al. (2007) extend the model to reflect a multi-port case. Song and Dong (2008) address empty container repositioning based on a threshold control policy in a cyclic shipping route. The later study of Song and Dong (2011) presents an LP formulation for the empty container management in a single service route with two policies for repositioning. The first point-to-point repositioning policy focuses on container balancing between any two pair of ports in the route. Then, a heuristic procedure is applied to reposition empty containers by coordinating all ports in the route and prioritizing decisions according to the cheapest port-pair policy. The model can be used for the decision-making process in the stochastic environment. It also incorporates the lost-sale penalty in the case when a customer demand cannot be satisfied immediately. Lee et al. (2011, 2012) apply a single-threshold policy to control the inventory and flow of empty containers in a multi-port system and use the simulation techniques to solve the problem. Later, the authors extend the proposed model in order to consider the joint empty container repositioning and container fleet sizing decisions. Song and Zhang (2009) use the model with inventory-based control mechanisms to study the impact of dynamic information of empty container repositioning. The later work of Zhang et al. (2014) extends the threshold control policy to the multi-port system.

2.3.2 Mathematical models for regional container management

The major part of the research work in the area of inland container management assumes a deterministic setting of the transport network and incorporates separate additional elements as container substitution, leasing, or street-turn. None of the existing studies comprise all of the possible activities in inland container management into a single model for the sake of computational tractability.

Table 2.3: Overview of regional container management models (based on the approach in Braekers (2012), p. 26)

		Approach			Modeling elements				
Model class	Author(s)	Deterministic	Stochastic	Simulation	Loaded & Empty flow	Street turn	Multi-type containers	Container substitution	Leasing
Empty container repositioning (ECR)	Crainic et al. (1993b)	•	•				•	•	•
	Choong and Cole (2002)	•							
	Olivo et al. (2005)	•					•		•
	Di Francesco et al. (2006)	•					•	•	
	Olivo et al. (2013)	•					•	•	•
	Yun et al. (2011)			•					
	Dang et al. (2012)			•					•
	Dang et al. (2013)			•					•
Depot direct and street turn movement	Jula et al. (2003)	•				•			
	Jula et al. (2006)	•				•			
	Chang et al. (2006)	•				•	•		
	Chang et al. (2008)	•				•	•		
	Ioannou et al. (2006)	•	•			•	•	•	
Cargo routing incl. ECR	Bandeira et al. (2009)	•			•				
Container allocation and Vehicle routing	Zhang et al. (2009, 2010, 2011)	•			•				
	Braekers et al. (2013)	•			•				
	Caballini et al. (2015)								
Depot location problem incl. ECR	Crainic et al. (1989)	•							
	Crainic et al. (1993a)	•							
	Gao (1997)	•							
	Lei and Church (2011)	•				•			
	Zhang and Facanha (2009)			•					

One of the early models for allocation of empty containers in the regional transport network is proposed by Crainic et al. (1993b). The authors describe the deterministic case with a single type and multiple type containers, including substitution possibility. Later on, the stochastic formulation of the model is presented to account for the uncertainty of demand and supply data. The proposed models offer a useful general framework for inland container management and are often used as a base for the further studies.

Basing on work of Crainic et al. (1993b), Choong and Cole (2002) present an integer programming formulation for empty container relocation in intermodal container-on-barge transportation networks and study the effect of planning horizon length on empty container management. The authors demonstrate that the longer planning period enables to produce a better result, as it encourages the usage of slower and cheaper transportation mode. Olivo et al. (2005) develop a deterministic operational model for managing empty containers on a continental scale over a weekly planning horizon with an hourly time-step. The authors also introduce a concept of macro-nodes, which comprise the information about supply and demand in specific zones, and thus, play a role of managing authorities that coordinate the information flow. Later on, Di Francesco et al. (2006) extend the model with container substitution possibility basing on the work of Crainic et al. (1993b), while Olivo et al. (2013) introduce the option of short-term leasing. All models are formulated as deterministic dynamic problems using mathematical programming approach.

Several studies address the problem of empty container repositioning using the simulation-based optimization approached. Thus, for example, Yun et al. (2011) apply a simple inventory control policy to reposition empty containers in an inland area between customers and hub terminals with random demand for equipment. Dang et al. (2012, 2013) extend this approach by introduction a more complex inland-depot system. The authors present several policies for container positioning from other ports, inland positioning between depots, and additional acquiring of containers from leasing companies. A genetic-based optimization procedure is proposed as a solution to the model.

The next group of studies focuses on modeling the street-turn movements in empty container management. Jula et al. (2003, 2006) approach the problem of dynamic empty container reuse analytically and develop optimization techniques to solve the problem. Inter-depot repositioning is not considered. The later studies of Chang et al. (2006, 2008) and Ioannou et al. (2006) extend the model by incorporating multiple container types with substitution option and address the stochastic case for a static single-commodity problem. All models demonstrate that the incorporation of street-turn option in empty container repositioning can significantly reduce total management cost.

Some authors connect empty and loaded container flows into one problem, trying to approach the normal and reverse container distribution in inland transport network simultaneously. Thus, for example, Bandeira et al. (2009) propose a two-stage model, which at first prioritizes and adjusts transport requests considering available empty container supplies, and then statically optimize total transportation costs. In the regions with strong imbalance, the proposed method will be, however, less efficient since it will lead to backlogging of unfulfilled demands in the surplus/shortage nodes. No leasing option is taken into account.

The recent research studies also try to address the problem of regional empty container movements together with the vehicle routing decisions. However, the problem formulation is typically kept simplified for the sake of computational tractability, and the meta-heuristic solutions are applied in order to treat the realistic-size instances. Zhang et al. (2009) consider an inland network with a single container terminal, several vehicle depots with empty container stock, and several customer locations. The problem is formulated as a multiple vehicle travelling salesman problem with time windows that seeks to minimize the total traveling time. This problem is later extended to a network with multiple container terminals in Zhang et al. (2010). Further on, Zhang et al. (2011) return to the problem formulation with a single depot and single terminal but assume that a number of empty containers available at the depots are limited. The authors demonstrate that the introduction of this constraint leads to a much higher complexity. Braekers et al. (2013) propose a similar model. However, the authors assume that the vehicle may leave for another task, and an empty container that becomes available at the consignee's location may be picked up by another vehicle. Caballini et al. (2015) introduce another aspect into the problem. The study presents a mathematical approach for combining multiple trips in a port environment by considering the opportunity of carrying two 20-ft containers simultaneously on the same truck and by using the same load unit of possible. In this way, more than two nodes can be visited with the same vehicle within the same route, and thus, a number of total empty container movements can be significantly reduced.

Finally, a separate group of studies addresses the optimization of regional empty container repositioning as a part of inland depot location problem. Such approach is introduced for the first time by Crainic et al. (1989) and developed further by Crainic et al. (1993a). The authors focus on the location of several depots in the inland region in order to serve all customers with empty containers taking into account the possibility of inter-depot repositioning. It is emphasized that the movement of large consolidated flows between depots is more economically efficient than the repositioning of separate containers between depots and remote customers, and thus, must be incorporated into the location-allocation model. The problem is formulated as a mixed-integer program. Later studies address the solution approaches such as tabu-search heuristics (Crainic et al., 1993c), branch-and-bound procedures (Crainic et al., 1993a; Gendron and Crainic, 1993, 1997) and dual-ascent procedures (Crainic and Delorme, 1993; Gendron and Crainic, 1995). The extension to the proposed model is presented by Gao (1997). The author presents the depot location problem with inter-depot balancing requirement in a dynamic multi-period modeling framework, emphasizing that such framework is a crucial condition for modeling of the balancing activities. The model also incorporates the street turn movements of containers using selected artificial-depot procedure. The uncertain nature of container demand and supply is handled through simulation. Lei and Church (2011) present three strategic-level models for locating empty container depots in the port hinterland with a purpose to reduce the repositioning cost. The model incorporates the option of street-turn.

Zhang and Facanha (2009) reduce empty container repositioning costs through optimal depot location with analytical methods. A proposed method shows good results but is applicable only for the North American intermodal transport system.

2.3.3 Mathematical models incorporating global and regional levels

There was little attempt to combine maritime and inland container movements in a single model. The main obstacle for this is the complexity of both networks and their large dimensions. As a result, the computational tractability of real-world cases is not guaranteed.

An attempt to integrate global and regional managerial levels is made by Erera et al. (2005). The authors propose a model for simultaneous routing of loaded containers and repositioning of empty equipment in the shipping network of customers, inland container depots, and ports. Containers are stored only in inland depots, where the decisions on inventory balancing are made. The model is formulated as a deterministic multi-commodity network flow problem over a time-expanded network, and solved using commercially available integer programming software. The authors state that it is now computationally feasible to solve realistic instances of more complex problems. The proposed case study considers, however, a rather limited transport network with only 10 ports and 600 TEUs in operation. Despite this, the model demonstrates that the integration of loaded and empty container movements on global and regional level enables a more cost-efficient management.

The later study of Meng et al. (2012) integrates an inland leg of the container transportation process into the maritime shipping network while addressing the problem of global service network design. The authors propose a mixed-integer linear programming model that seeks to minimize the total operating cost of the transport network. However, several assumptions are made in order to simplify the problem and be able to solve it for a more realistic large-size instance. The inland part of the network is presented only by inland customer locations and a predefined set of possible intermodal paths between customers and candidate export/import ports. Inland depots for container storage or any empty container movements between depots, customers, and ports within an inland area are not considered. The routing of the loaded containers is implemented using a hub-and-spoke network structure. For the port-to-port routing, a set of possible routes is enumerated for each customer demand considering the allowed number of transshipments as well as the maximum allowed transit time and distance. Inland legs are then combined with the maritime routes taking into account a set of candidate export/import ports for each container shipment and the maximum allowed transit time for the inland-to-inland route. Empty container flow is formulated in the model as a path flow on the possible intermodal routes in inland, and as a leg flow on the legs of ship routes in the maritime service network.

The earlier study of Gao (1994) incorporates inland aspects of container transportation into the maritime shipping network through the introduction of container devanning time. This term is used by Hyundai Merchant Marine Company. In Gao (1994) devanning time implies the time needed for la oaded container to be unloaded, unpacked, and returned to a depot for reuse. The author integrates this parameter into the proposed model for container allocation in the shipping network. He argues that it is an important element in the model since not all containers unloaded in a port can be reusable immediately due to a need of further inspection, cleaning or repair. Consequently, before applying any optimization model, the "container selfproduction process" must be analyzed with a purpose to identify the availability of empty equipment. The same approach is adopted by Moon (2010).

It must be noted that even though the devanning time used in both studies (Gao, 1994; Moon, 2010) allows to specify when containers become reusable for empty container repositioning, it does not reflect any round trips to/from the customers within the port service areas. In reality, however, the inland service region of the ports can be fairly large: e.g. for the ports of North America. As a result, the prolonged turn-around time of containers in the inland region can affect the availability of containers for the further usage. Moreover, loaded containers can be emptied and reloaded in the inland region since the distant customer clusters can have an inland container depot close by. The devanning time will fail to model such situation.

An inland transportation time of containers is also incorporated into the global model by Dong and Song (2009). However, the main focus of the study is the container fleet sizing. The operational policy for empty container repositioning is included only as supporting aspects in the modeling. The model is solved using simulation-based approaches and is used to identify the quantitative impact of inland transport time on strategic inventory-related decisions.

Thus, the conducted literature review shows that only a few studies try to incorporate regional aspects of container transportation into the global container-related decisions despite the obvious interconnection between managerial levels.

2.4 Research gaps and opportunity for further research

The problem of container management has been addressed by an extensive number of research works, which have been typically focusing on the global and regional scales separately. Based on the literature review, it can be concluded that the predominant number of models for global container management is formulated as deterministic dynamic problems using mathematical programming approach. Future work should focus more on stochastic nature of shipping process. Several other opportunities for further research are identified:

- **Incorporation of short-term leasing option:** Almost all studies involve mainly long-term leased containers, which are operated as owned inventory. The aspect of the short-term leasing needs more consideration since it significantly affects the company's dynamic operations, especially in stochastic situations. It must also be noted that the short-term leasing option comprises a range of specific conditions related to the requirement of the minimum lease duration, the drop-off quotas, which vary basing on container volume at carrier's disposal, etc.

- **Comparison of short-term and long-term leasing decisions:** An interesting research direction is a comparison of the short-term leasing decisions on the extended planning horizon when the long-term term leasing can be more reasonable.

- **Incorporation of slot purchasing option:** Almost no studies incorporate the option of slot purchasing for repositioning of empty containers. At the same time, it may have an effect on the leasing decisions, and thus, needs more careful consideration.

- **Joint management of loaded and empty containers:** Only a few studies have explicitly considered both loaded and empty container flows in the container repositioning models. The main challenge is associated with the computation complexity arising from the increased number of variables. However, the empty container flow directly derives from the loaded movements. It may also be reasonable to forgo certain cargo if its revenue cannot offset the associated repositioning cost.

- **Shipping demand rejection:** It may be reasonable to reject certain customer orders due to several reasons. Vessel capacities might be inadequate for total transportation, the number of containers available for the short-term leasing is restricted, certain shipping directions are much less profitable, while the cost of empty container repositioning is very high, etc. Only very few studies address this issue in the models.

The models for inland container management are more complex due to a variety of aspects in the transportation process: e.g. container substitution, leasing option, street-turn and depot-direct movements, a need of container cleaning and repair, etc. Different studies are typically incorporate only separate elements in their models. Most of the studies optimize inland container management with a given demand for empty containers in each separate port. The availability of containers in the ports is, however, the outcome of regional management. The opportunities for the further research include:

- **Restriction of turn-around time of containers in the inland region:** The problem of speeding up the return of container equipment back to the port's region has been growing in relevance over last years for such regions like North America. Due to the large inland service network, the round trips to certain hard-to-reach locations may require a significant amount of time. As a result, certain shipping lines started to limit their inland services partially in order to speed up the turn-around time of their equipment. To the author's knowledge, there have been no studies addressing this issue.

- **Shipping demand rejection:** All existing mathematical models assume that all shipping demand must be satisfied, no load rejection is allowed. In practice, however, some ocean carriers decide to cut down the number of customer locations served due to time or cost reasons, which is particularly relevant for North American inland service network.

- **Street-turn option:** Several studies address the street-turn option in container management in a small port's area. Only a few models incorporate the direct movements between consignees and shippers on a larger regional scale.

Finally, there has been little research on analyzing the effect of regional aspects of container management on the global container-related decisions. The interconnection between inland and maritime transport networks needs more consideration in the models.

3 Overall framework for container management optimization in transport networks

3.1 Holistic view of container management process in an ocean carrier's transport network

Container management in the whole transport network does not represent a centralized system in practice. It consists of a Head Office, responsible for the maritime transportation, and a number of regional offices throughout the world, which are responsible for the inland transport services (Di Francesco, 2007, p. 42).

When a customer has a demand for the overseas shipping, it contacts a regional office, requesting a certain number of empty containers for the shipment between specific ports. If the freight rate of the sea shipment is acceptable, the customer can pick up empty containers from the carrier's depot, and then present them loaded with cargo at a port of departure. All inland movements are organized either by the customer himself or by the regional office. If the carrier's inland service (carrier's haulage) is chosen, the regional office selects a depot for empty container pick-up and gives the instructions to a partnering trucking company about the location, where containers need to be presented for loading, delivery time, and all further movements. It is the regional office's main responsibility to optimally organize vehicle movements with empty and loaded containers in order to avoid unnecessary empty trips.

In case of the inadequate container inventory in the depot to serve the customer, the regional office may adopt different measures: a) reposition empty boxes from other depots in the region; b) substitute the demanded containers with other types; c) request empty boxes from the Head Office; or d) lease additional equipment from leasing companies. The latter needs, however, an approval of the Head Office, because the carrier typically prefers to use its owned containers rather than acquire new equipment.

Finally, when all arrangements are done, the regional office presents to the Head Office a list of loaded containers to be shipped from a port, a number of empty containers lacking in the region, or a number of containers returned to a port unused. Based on this information, the Head Office now needs to make decisions on: a) how to place the export containers in a vessel, b) how many empty containers to assign to the global repositioning, or c) how many empty containers to unload from a vessel in order to mitigate the inventory deficit in a region.

In the case when the customer orders the carrier's haulage for the end carriage of export shipment, the Head Office sends the corresponding information to a regional office in the destination area. The organization of further inland container movements is similar to the described pre-carriage but with the reverse direction.

Thus, knowing exact areas of responsibility for different managerial units, container management in the whole transport network is now presented as a holistic process in terms of Control Theory (Figure 3.1). A tactical perspective is adopted for the presentation.

The managerial environment is divided into several control areas on different levels: from global to regional and local. Global level represents the maritime shipping of containers between ports, while regional level displays the inland movement of containers within a certain region: e.g. Europe, North America, Asia, etc. A region can be further divided into specific local levels: e.g. U.S. West or East Coast, Midwest, etc. Each separate managerial area represents a sub-system, controlled by a respective unit.

The Head Office of a liner shipping company controls the flow of empty and loaded containers between the ports on a global level. Knowing certain input values of transport demand, as well as information about container availability in the ports provided from the regional offices, the Head Office aims to achieve the desired outcome – maximum profit or minimum cost from transport activities – through certain manipulations with the control parameters (e.g. empty container repositioning, leasing decisions, or demand rejection). Regional and local offices are focusing only on the container flow in the port's inland areas, and aim to make optimal decisions on inland container management having the given input values of transport demand and ocean carrier's inland services.

In this way, the flow of containers goes through several sub-systems, which control, coordinate, and update the data about transport process on its corresponding level. Vertical communication enables the information flow between the Head Office and the regional offices. The Head Office provides the instructions regarding its managerial policies in the inland areas to the respective managerial units. For instance, the ocean carrier can set a tight restriction on the time that containers are allowed to stay in the region. Then, regional offices need to organize all inland movements, knowing that import containers must be returned back to the ports reloaded with export cargo or empty no later that in a certain turn-around time. The policy regarding leasing sets the magnitude of leasing allowed in the region or the magnitude of leased containers that must be off-hired in the inland area.

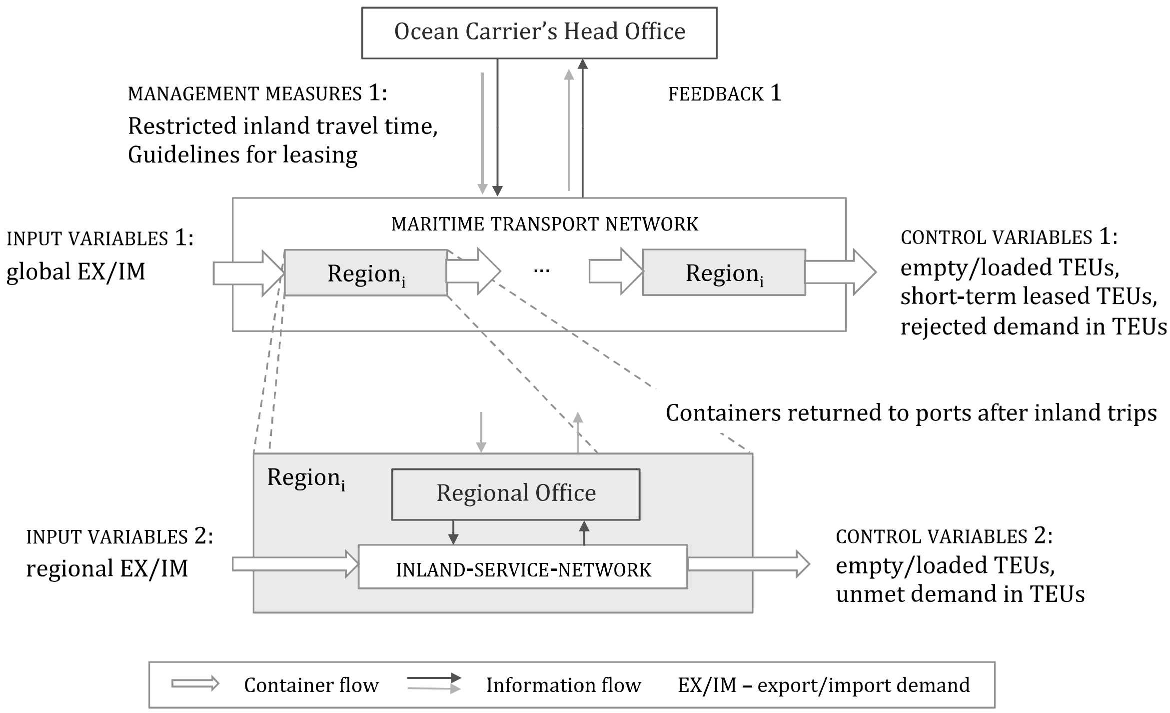


Figure 3.1: Holistic view of container management adopted in the thesis

Regional offices provide the Head Office with the information on how many loaded and empty containers are available in the ports at a time. It must also be noted that there is no direct exchange of the information between offices from different regions. Instead, all data goes to the Head Office, which organizes all inter-regional container movements. At the same time, the local offices within one inland area can interact with each other through horizontal communication.

For the smooth container flow in the whole transport network on an operational level, a constant interactive communication between all offices is needed. At the same time, the planning of container movements on the tactical level does not require the hourly or even daily update of information. Thus, in order to plan the magnitude of container flow on the global level, it is enough to know certain averaged parameters or characteristics of the port's hinterland. For example, it can be enough to know that all import containers entering the region will return to the ports empty or reloaded in a certain interval of time. An average turn-around time can be defined using additional empirical analyses. Based on such studies, as well as historical data, it is also possible to predict a typical distribution of inland container flow back to the port's areas.

3.2 Model system

Based on the described process of container management, a certain approach is proposed for the optimization of global and regional container movements. It implies the development of two separate sub-models for maritime and inland transport networks, incorporating specific common parameters, which enable the interconnection between managerial levels and integration of the results (Figure 3.2). The averaged parameters are given as input data, and include information on: 1) weighted-average inland travel time of containers, 2) weighted-average turn-around time of containers in the region, and 3) portion of all import containers in the region returned to specific port after the round trips. The latter parameter is applicable only in the case when the ports share the same inland service area and exchange containers between each other. For instance, the ports on the U.S. West and East Coast have common inland service area in the Midwest. As a result, certain containers that arrive to the inland area from the West Coast can be returned loaded or empty to the ports on the East Coast. The ports with separate service areas will have equal headhaul and backhaul container flows.

The Maritime Model uses certain parameters to get the information on container availability in the ports. Weighted average inland travel time provides the information on when and how many import containers will be available again for reuse, and the model then optimizes the repositioning of empty containers in the global shipping network. If the ports are located in container shortage area, the import flow is added to the flow of empty containers. A portion of containers in the region returning to specific port can be adjusted if needed, using additional parameters. The Inland Model uses time-related parameters as guidelines to inland container management. It optimizes empty container movements in an ocean carrier's inland service network having a certain restriction of weighted-averaged turn-around time of containers in the region. If any customer demands are left unmet due to time or cost reasons, the distribution of regional container flow may be affected. In this case, a portion of import containers in the region returned to specific port after the round trips must be corrected based on the Inland Model's output. The impact of such changes on the global management is incorporated into the objective function of the Inland Model.

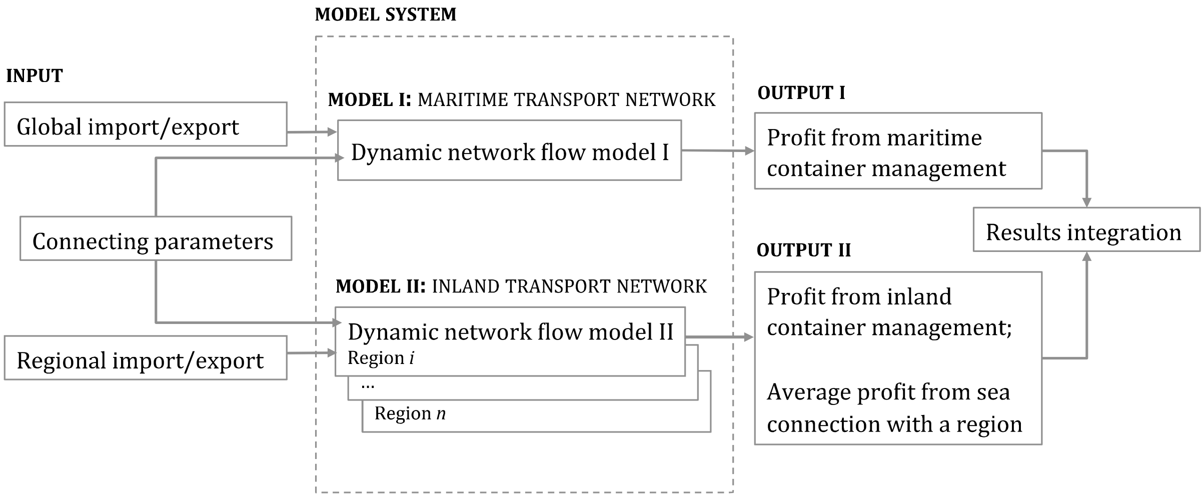


Figure 3.2: Holistic approach to the tactical optimization of container management in ocean carrier's transport networks

Both problems are formulated as dynamic network flow models that seek to maximize the total profit from container management in the respective transport network. The restriction of inland transport services can lead to the loss of customer orders on the whole shipping chain, and thus, affect the profit from a maritime sector. As a result, the Inland Model additionally incorporates an average profit from the seaport connection with a region as a part of its objective function. This component considers a profit from import/export shipments on sea legs, and an average repositioning cost of empty container surplus out of the inland region. In this way, if there is any change in inland service network or in regional container flow, the model enables the evaluation of the effect on the sea shipping, and the integration of the result into the output of the Maritime Model.

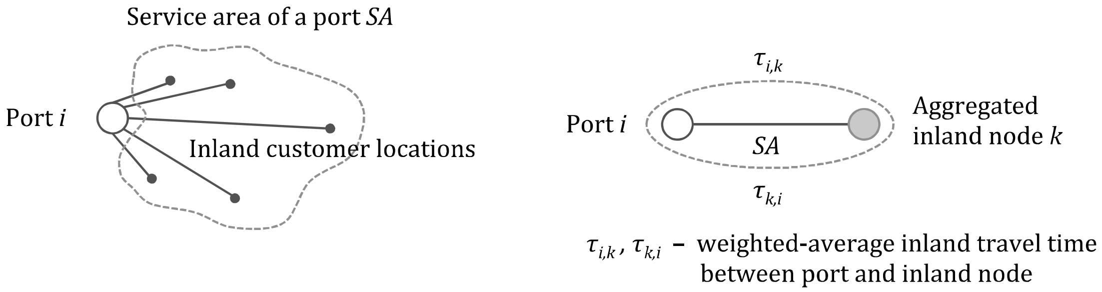
Finally, it must be noted that both models are proposed for tactical planning. They define only the magnitude of empty and loaded container flows in the network, providing the optimal guidelines for leasing, evaluating the optimal range of inland services, etc. Thus, the models can use aggregated container flows, simplified or aggregated transport networks, as well as averaged time and cost parameters as their input data.

A more detailed description of both models is presented in the following sections.

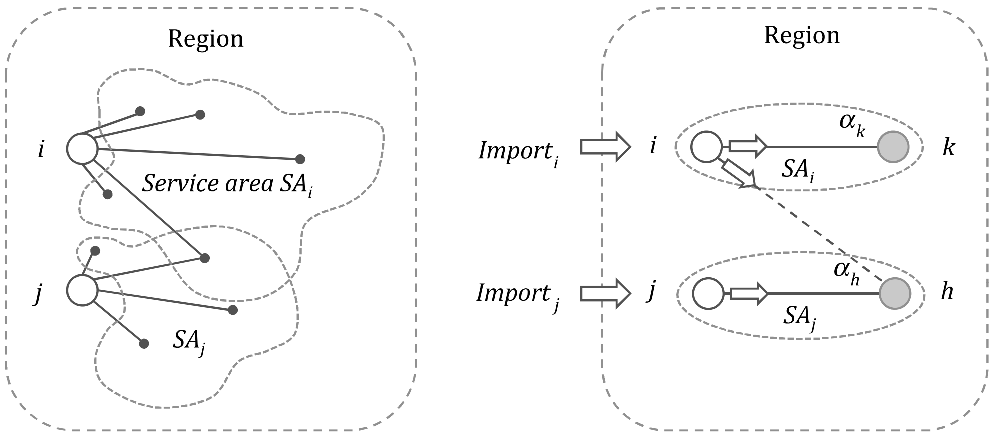
3.3 Model I: Maritime transport network

It is assumed that each port of the global shipping network is associated with a specific inland service area that reflects an aggregated cluster of import and export customers served by a port (Figure 3.3a). The inland area is represented in the model by an additional node grouped with its corresponding port in the transport network.

All import containers arriving at a port need to go to the inland area to be unloaded. Only then they can be reused for export shipments or returned back to the port empty. If containers are not enough for the export cargo, additional equipment needs to be repositioned in from other ports and sent to the inland area for loading. In this way, all containers arriving at a port become available for the further usage only in a certain time – weighted-average transport time from the port to the inland service area. The transport time of headhaul and backhaul might not be equal in the model. It is also assumed that the balancing of export and import container flows is done in the inland region.



a) A single port in a region and its corresponding inland service area



b) Several ports in a region with their intersected inland service areas

Figure 3.3: Simplified presentation of port's service areas in the inland region

It must be noted that several previous models consider only "devanning time" – the time, when import containers become reusable again after inspection, cleaning or repair (Gao, 1997; Moon et al., 2010). In this case, the balancing of container in-/outflow is done in the ports without any consideration of inland travel time, which might take a week or longer in certain regions (e.g. in North America).

When different ports belong to the same region (e.g. U.S. West and East Coast ports), they might also have a common service area, and import containers arriving to the inland region from one port might not always return to the same port (Figure 3.3b). In this case, the model can be extended in order to incorporate the corresponding regional container flow. It will be assumed that the common service area of two different ports is included in both of their inland nodes. Then a portion of containers that enters the region through one port but leaves through another one is added to the inland node corresponding with the port of exit. In order to reflect this situation in the model, a share α_k is introduced for each inland node k. It assigns a portion of all regional import containers to the inland node that is linked to the port of container departure.

Thus, the global container management is performed in the transport network of ports and their corresponding inland nodes (Figure 3.4). A port and its inland node represent a single port's service area. The ports, however, serve only as entry/exit gates for the container flow that is being balanced and stored in the inland nodes. Additionally, the ports and their inland nodes that belong to the same region are grouped together, which enables the exchange of containers between these ports.

Having a certain input data on global transport demand, and the weighted-average parameters characterizing the inland trips of containers, the Maritime Model proposes an optimal set of decisions on global container management with a purpose to maximize the total profit from container shipping ($Profit_{\mathrm{M}}$). The main decisions considered in the model refer to: 1) how to reposition empty containers between ports in order to meet the transport demand; 2) which transport demand may be rejected in case of inadequate container inventory or vessel capacity; 3) how many containers can be leased for the short-term period, and in which areas; and 4) how many leased containers must be returned back to the lessors, and in which areas.

While making decisions on the short-term leasing, the following specific conditions are taken into account: 1) restriction of total leasing within a certain planning horizon, 2) requirement of the minimum average lease duration, 3) specific drop-off quotas in the ports. The return quota is adjustable every month based on how many leased containers are available at carrier's disposal each month.

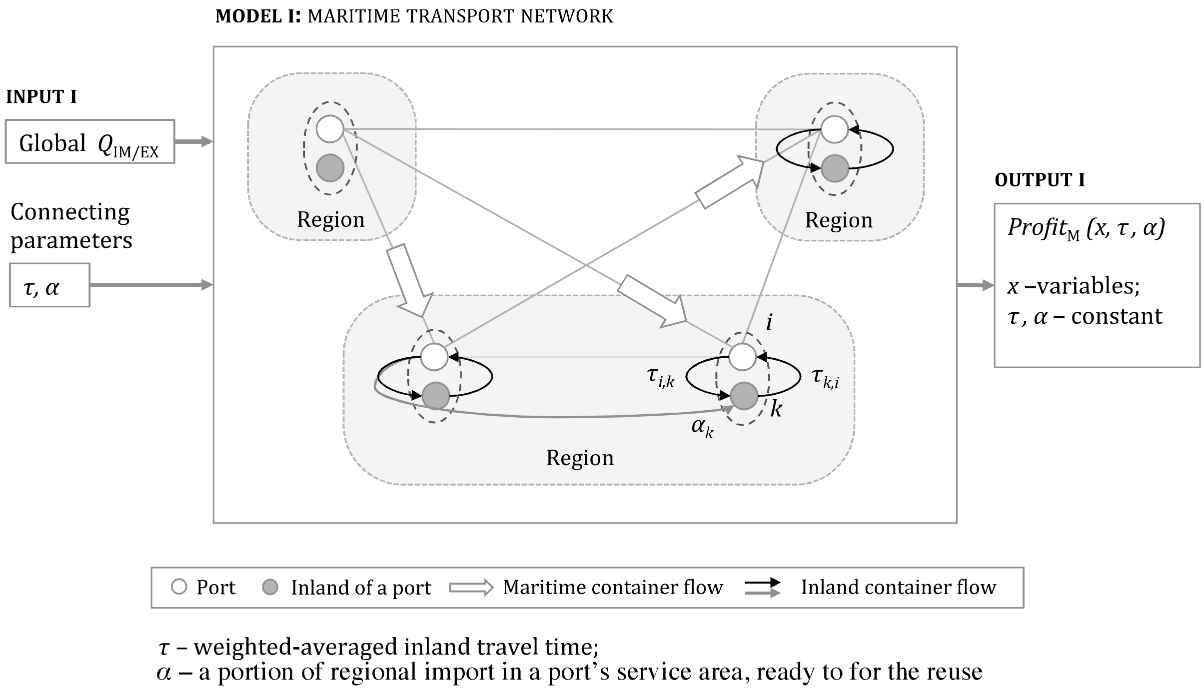


Figure 3.4: Approach to the tactical optimization of global container management

3.4 Model II: Inland service network

Container management on the regional level is performed in the ocean carrier's inland service network, which consists of ports, customer locations served on carrier's terms and inland depots for empty container drop-off or pick-up (Figure 3.5).

Each port serves a certain area with import and export customers. The range of possible import and export transport services along with their respective rates, costs, and transport times are known. When the import containers arrive from a port to a customer site, it is assumed that they are immediately unloaded and become available for further reuse. In a similar way, when empty containers are supplied to an export customer's site, they are immediately loaded and become ready for the inland haulage to the port for the ongoing sea shipping. As a result, every import shipment is associated with a supply of empty containers, while every export shipment presents a demand for empty containers. Knowing the data about container supply and demand, the model aims to organize all empty container movements in the transport network with a purpose to satisfy the customer demand for inland haulage. At the same time, it must be considered that weighted-average turn-around time of containers in the region is limited. All containers that enter the region need to return back to the ports empty or reloaded no later than in a certain interval of time set by an ocean carrier. In this way, the Maritime Model has an expected minimum number of empty boxes in the ports and can decide, how many of these empty containers will be used for global repositioning.

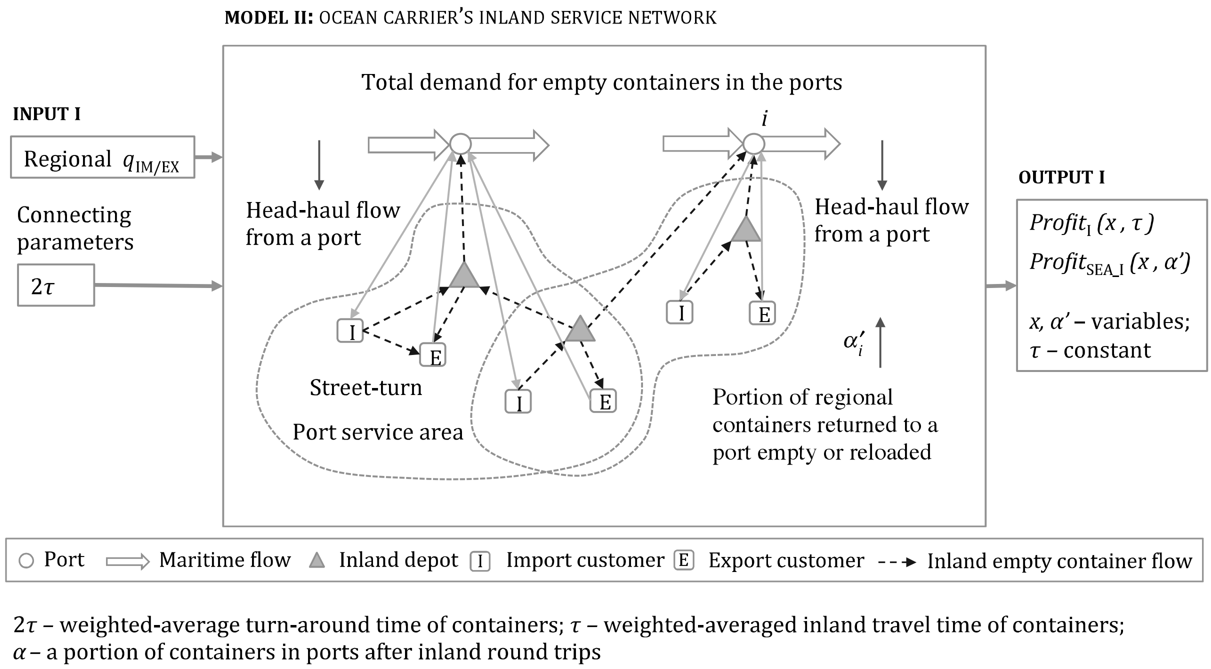


Figure 3.5: Approach to the tactical optimization of regional container management

It must be noted that the transport process of loaded import and export containers is not modeled. Instead, every empty container supply and demand is associated with a certain profit from import and export inland haulage, respectively, and a certain transportation time between a customer location and a port. Thus, the links between ports and customer locations in Figure 3.5 do not represent an actual movement but carry the information about the inland haulage. As a result, when planning all empty container movements in the network, it is possible to define a total profit from inland container management and an averaged container turn-around time in the region.

Empty container movements, which are optimized in the model, include:

- Repositioning of unused containers back to the port. Since the model considers a far away inland region, empty containers are dropped off at inland depots first, and only then are shipped in a batch to the ports. This movement is done by rail taking into account the train schedule.
- Truck drayage of empty containers between customer locations and inland depots.
- Inter-depot repositioning in case of inadequate container inventory in certain depots. This transportation is also done by rail and is possible only according to the train schedule.

A portion of empty boxes can also be directly exchanged between import and export customers. The street-turn or the direct transport of empty container from a consignee to a shipper is the most profitable option for empty container management since it avoids the unproductive moves to and from inland depots. However, the planning of such movements is connected with a high uncertainty of data. Containers at a consignee's site may not be reusable right after the unloading of the cargo. They might need an additional inspection, cleaning or repair. The delays are also possible at a customer location. As a result, according to several studies (Crainic et al., 1993b; Wolff et al., 2012) a portion of street-turn containers may reach up to a maximum of 5% of the total import container flow.

When the inland transport service for certain customers results in an excessive turn-around time of containers or is associated with a high empty repositioning cost, the ocean carrier can reject such requests for carrier's haulage. In this case, the model assumes that a customer can choose another shipping company, which can organize the whole transport chain for him. Consequently, the ocean carrier can lose the profit on both inland and sea legs of the shipment. The rejection of export shipments also increases the surplus of unused empty containers that must be repositioned out of the region at ocean carrier's own cost. As a result, the option of transport service limitation, introduced into the Inland Model may affect the distribution of regional container flow back to the ports, which constitutes an important input data for the Maritime Model. A portion of regional import containers returned back to the ports empty or reused (α_i') must be then recalculated based on the output of the Inland Model using the following formula:

$$\alpha_i' = \frac{EX_i + EmptyOut_i}{\sum_{i \in Ports} (IM_i + EmptyIn_i)},$$

where EX_i, IM_i is a number of export and import containers, respectively, transported in the inland region from/to a port, $EmptyOut_i$ is a number of empty containers returned to a port for global repositioning out of the region, and $EmptyIn_i$ – a number of empty container inflow into the region through a port. The latter component is given as input data, if the model is applied to the region with container shortage (e.g. Asia). Otherwise, this parameter will be absent.

In order to evaluate the effect of the inland service restriction on the sea connection with the region, the additional averaged parameters related to the sea shipping are introduced into the model's formulation. Every demand for import and export inland haulage is characterized by a certain profit from the shipment on the sea leg. Every empty container that must be repositioned out of the region to another container shortage area is associated with an average repositioning cost. As a result, the ocean carrier can decide which customer locations to serve and how to organize all needed empty container movements with a purpose to maximize the profit from inland service network ($Profit_{\text{I}}$), considering, at the same time, the possible effect on the sea connection with a region. The change in the profit from the seaport connection with an inland region is calculated as follows:

$$\Delta Profit_{SEA\_I} = P_{IM} + P_{EX} - (P'_{IM} + P'_{EX}) + C'_{ECR} \ ,$$

where P_{IM}, P_{EX} is a profit from initial demand for import and export shipment, respectively, P'_{IM},P'_{EX} is a profit from served import and export shipments, respectively, after service limitation, C'_{ECR} is an average cost of global repositioning of additional empty containers, which are left unused due to rejected export shipping demand.

3.5 Integration of models and their results

In order to apply the proposed models as a system and integrate their results into one output, a correspondence between the maritime and inland transport networks is required. For instance, certain input data must match on both, global and regional levels. Further on, the following main aspects must be considered to enable the integration of the models.

Port nodes: The port-nodes in the Maritime Model and Inland Model must correspond with each other. If certain ports in the global shipping network are aggregated with the purpose of network reduction, the disaggregation techniques (Balas, 1965; Francis, 1985; Zipkin, 1975; Zipkin, 1980) must be later applied in order to define the volume of container flow for each separate port. These data can be then used as an input for the Inland Model.

Inland node and inland region: In a similar way, an inland node in the global shipping network must correspond with a region considered in the inland transport network. There must also be a correspondence between import and export volume given in the Maritime Model, and the inland flow of import and export containers given in the Inland Model.

It must be, however, noted that a port in the maritime network can serve a large-scale region with different service areas: from the immediate area in the proximity of the port to the far-away inland locations (Figure 3.6). In this case, the whole region must be correspondingly presented in the Inland Model. The entire region with its total container flow can also be split up into different areas, and the inland travel time can be defined as a weighted-average value for each sub-region. Then the Inland Model can be applied only for specific sub-region in order to study this area in more details. The demand for inland haulages in the Inland Model will represent only a portion of the total regional container flow. The restriction of the turn-around time of containers will be based only on travel times within that area, while the Maritime Model will consider an average turn-around time of all regional containers, weighted according to the flow in each sub-region.

In the case when a chosen sub-region interacts with the other inland areas, a portion of empty containers can always be subtracted or added to the total inventory in the region. In order to enable such exchange of containers with the outside environment, a "dummy node" can be introduced into the Inland Model. As a result, the Inland Model can optimize container movements within a sub-region, while the Maritime Model uses the data for the whole region.

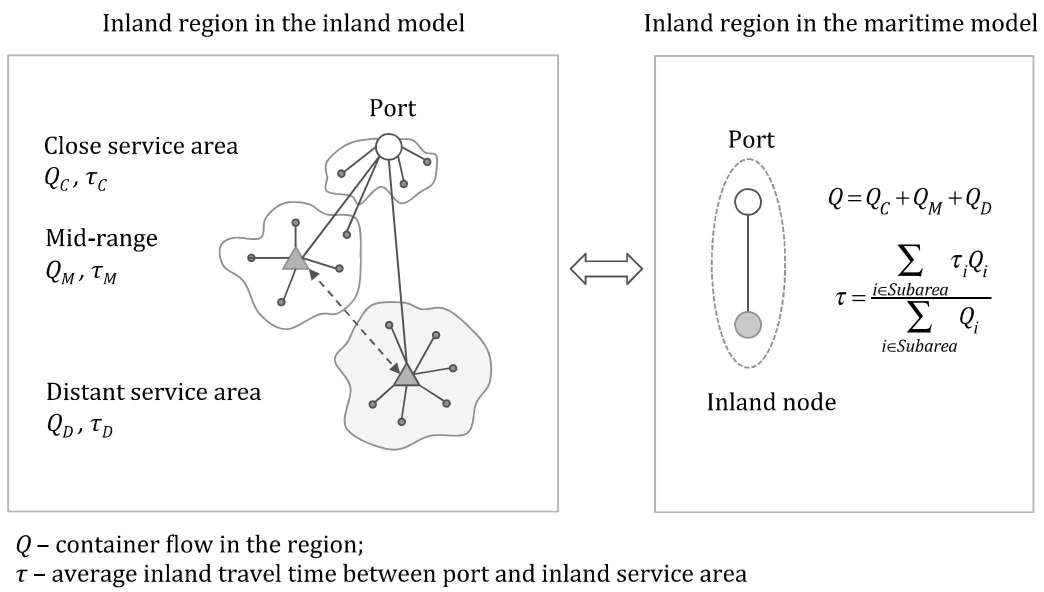
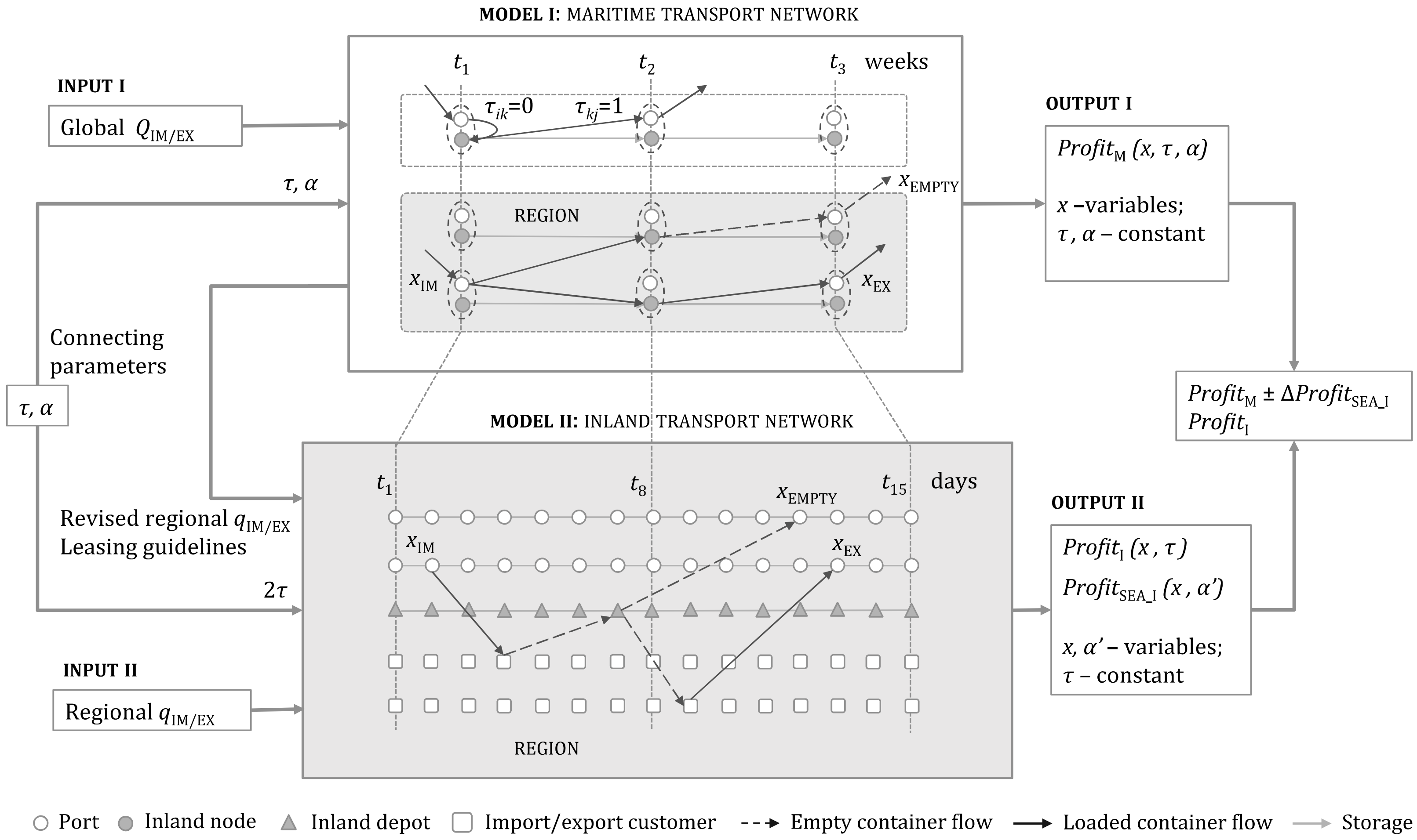


Figure 3.6: Presentation of an inland region in the Maritime and Inland models

Planning horizon and time unites: Both models are formulated as a dynamic network flow model, which incorporates a rolling horizon approach to reflect the information update. The rolling horizon implies that an operator makes the decisions on container movements for a fixed horizon [1,*T*], divided into discrete periods of time (see Figure 3.7). The problem is then solved for each period, but the implementation of decisions is done only for the first interval of time. After the existing information about the future periods is updated or revised, the model is run again. And again only the most immediate decisions are implemented.

The integration of the results from both models requires the equivalence of the planning horizons in the Maritime and Inland Models. The length of the time interval in the Maritime Model must be fixed considering the greatest common divisor for all travel times between nodes of the shipping network. Furthermore, the time interval in the Maritime Model must also be divisible by the value of the time interval in the Inland Model.



τ – weighted-averaged inland travel time of containers; 2τ – weighted-average turn-around time of containers in a region;

α – a portion of regional import containers that will return to a port's service area empty or reused

Q, q – total global and regional shipping demand, respectively; x – number of containers shipping in the transport network

Figure 3.7: Interrelation of results of the maritime and inland container management models

Figure 3.7 demonstrates a small example of the global and regional transport networks in their dynamic presentation, where all physical nodes are repeated in time. The models for global container management typically fix the length of a time interval in a planning horizon equal to a week. The arrival of all vessels to the port can be aggregated and set for the beginning of every week, while the departure of all vessels within a week is respectively aggregated and set for the end of every time interval. The minimum average inland travel time of containers in the Maritime Model equals one week, which results in the 2-weeks average turn-around time of containers in the region. In the case when containers return back to the ports earlier, the following simplifications can be made. It can be assumed that the time of the headhaul in the region equals 0, while the time of the backhaul equals 1 week. Such simplification can be justified by the fact that the return trips of containers back to the ports are typically longer. Emptied import containers are dropped off at first in the inland depots, and only when the shipping request for export is known, empty containers are sent to a new customer for loading and are hauled to a port afterward.

The Inland Model has a much smaller transport distance and shorter travel times between nodes of the network. As a result, a shorter time period (e.g. a day) is required for the planning of all inland container movements.

It must also be noted that the import and export flow in the ports of the Maritime Model is aggregated for the beginning and the end of the week, respectively, while the arrival and departure of the shipments in the Inland Model can be done at any time within a week interval. Correspondingly, empty containers in the Inland Model can be returned back to the ports at any time during the week according to the actual departure of the vessels. However, the total travel time of all containers in the region must not exceed the fixed value of weighted-average turn-around time, which also corresponds to the value of inland travel time used in the Maritime Model.

3.6 Summary of the optimization approach

The Maritime and Inland Models can be applied both separately and as a system. In the latter case, the common averaged input parameters that appear in both models enable the coherence and interrelation between container management on global and regional levels. A weighted-averaged container turn-around time in the region ensures that a surplus of all empty containers in the inland area will be returned back to the ports in the Inland Model and that an exact minimum number of empty boxes will be available at a certain time moment for the planning of the global repositioning in the Maritime Model. In the case when the ports of the global shipping network belong to the same region and exchange the containers on the regional level, the Maritime Model can be further extended with an additional parameter that accounts for the redistribution of regional container backhaul flow between the ports.

As a result, the coordinated global and regional container management allows combining the results of the profits obtained from different transport networks ($Profit_{\mathrm{M}}$ and $Profit_{\mathrm{I}}$). The following output of the Maritime Model can also be forwarded and incorporated into the regional container management:

- Revised demand for inland haulages, in the case when certain unprofitable global import/export shipments are not served;
- Guidelines for leasing in the regions resulted from the strategies on leased container deployment in the global shipping network.

In the case when the inland service simplification in the Inland Model brings changes in the volume of inland haulages or in the magnitude of empty container flow, the financial effect on the sea connection with a region ($\Delta Profit_{\text{SEA\_I}}$) can also be determined and integrated with the results of the maritime container management. After the changes in the inland service network are adopted into the liner shipping operation, the global shipping demand must be revised considering the lost customer orders, and the portion of empty containers in the ports after the round trips is corrected based on the new distribution of inland container flow.

4 Optimization model I: Maritime container management with short-term leasing consideration

4.1 Assumptions of the model

- An ocean carrier manages a homogeneous fleet of 20-ft containers. All 40-ft containers can be regarded as 2 TEUs considering their dimensions. As a result, all containers can be summarized by the net container inflow and outflow at a port in a time. Additionally, only Full-Container-Loads are considered in the model. Shipping demand for Less-than-Container-Load, which requires aggregation, disaggregation, or sorting operations at a container freight station, is not included in the model.
- Loaded containers are moved in the transport network using specific liner services. No transshipment between services is allowed in the model.
- Empty containers are not defined by any origin or destination ports, and thus, they can be moved in the transport network using any liner service. As a result, an aggregated network is presented for the empty container repositioning in the model. The time and cost of a voyage between two ports are defined as an average time and an average cost of all services with a given voyage. Vessel capacity for the shipping between two ports is presented as an accumulated capacity of all vessels sailing between given ports.
- Vessel capacity is limited.
- When a customer makes an order for the shipping, an ocean carrier needs to provide a necessary quantity of empty containers, which must be then picked up from a depot, moved to a shipper, loaded, and delivered back to the terminal for the sea shipping. In a similar way, loaded containers that arrive at a port need to be hauled to a consignee, unloaded, and returned back empty to an inland depot or a port. However, for the sake of simplicity, it is assumed that container inflow and outflow is balanced in a port's area, and all empty equipment is stored and presented available for transportation in

the ports. Container freight stations within a port, inland depots, or warehouses outside of a port are considered as one system.

- The inspection, cleaning, or repair of containers is not considered in the model.
- Not all demand must be satisfied.
- In case of container shortage, additional containers are available for the short-term leasing at any time. However, considering that leasing companies are trying to have only a small amount of equipment available for the short-term lease, the restriction of the total leased number can be added into the model.
- In order to prevent the excessive leasing of containers at the end of the planning period, it is also assumed that all short-term leased containers available at a carrier's disposal at the end of the planning horizon must be assigned to the off-hire. However, containers cannot be returned all at once due to the fixed off-hire quotas. As a result, the cost of leased containers kept beyond the horizon till their possible return is incorporated into the model.
- Finally, it is considered that the short-term leasing requires additional financial resources that will be tied-up for the period of lease duration. As a result, leasing expenses include the cost of capital, which could have presented an opportunity if it were invested elsewhere. Opportunity cost of capital tied-up in leasing is defined based on an interest rate of a deposit in a bank.

4.2 Network flow presentation

This section presents the model for the global container management putting a focus on the short-term leasing. For simplicity reasons, no inland travel time for containers is included into the model.

The problem is modelled as a dynamic network flow problem. Movements of containers are presented in a time-space network, where nodes denote the ports in a time, and arcs represent the container traffic between them (Figure 4.1). It must be noted that for simplicity reason, Figure 4.1 shows only the representative arcs instead of the complete network.

The flows of leased and owned containers are treated separately in the model. Thus, each port is represented by two separate inventory nodes for owned and leased containers. Straight lines between different inventory-nodes in a different time period depict the movement of loaded owned/leased containers from one port to another. Dashed lines illustrate the same movement for empty containers. The arcs between the same inventory-nodes in different time periods represent the storage in the ports within a time unit.

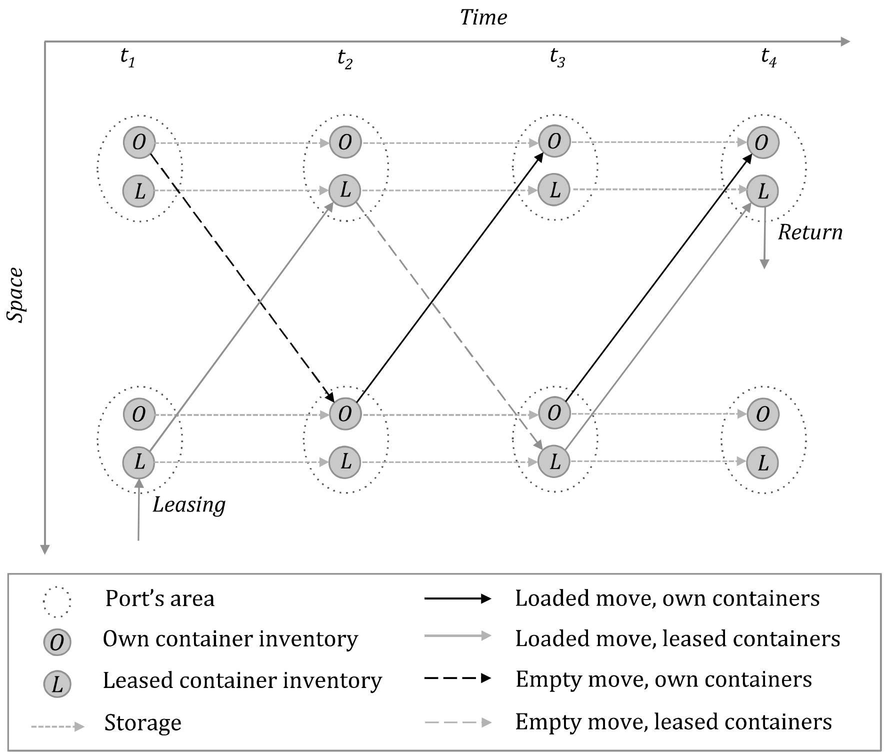


Figure 4.1: Container flow in a dynamic liner service network

The leasing of additional containers is possible at any time period in every node associated with leased container inventory. The arrows pointed toward inventory-node L depict leasing, and the arrows pointed away from L denote the return of leased containers back to the lessor, taking into account predefined off-hire conditions.

4.3 Mathematical formulation

A physical maritime network for container transportation is represented as a directed graph $G=(V,E)$

- Vertex set V defines ports
- Edge set E represents links between ports $(i,j)\in E$, $i\neq j$.

Let S be a set of aggregated weekly liner services representing the main shipping routes for loaded containers. A route of a liner service $s\in S$ is defined as a directed sub-graph $G_s=(V_s,E_s)$, $G_s\subset G$. Travel time of a link $(i,j)\in E_s$ of a liner service $s\in S$ is denoted by τ_{ij}^s. At the same time, empty containers are being repositioned using an aggregated network G, where the arcs of all liner services are combined together. Transport time of each arc $(i,j)\in E$ is denoted as τ_{ij}^0.

In order to account for the dynamic decision-making process for a planning horizon T the physical network G is converted into a time-space network with a set of nodes N and a set of travel arcs A.

- Each node $n\in N$ represents a port-time pair (i,t), where $i\in V$ and $t\in T$.

- Each travel arc $a=((i,t_1),(j,t_2))\in A$ represents a combination of two nodes (i,t_1) and (j,t_2) such that $(i,j)\in E$, $t_1,t_2\in T$, and $t_2=t_1+\tau_{ij}^0$.

Furthermore, all travel arcs originating at node n and all travel arcs ending at node n are listed in a set $\delta^+(n)$ and $\delta^-(n)$, respectively. The shipping cost c_a^0 of an aggregated arc $a\in A$ is defined as a minimum over the costs of all liner services with a voyage on arc a, while the vessel capacity cap_a^0 on arc $a\in A$ is calculated as an accumulated capacity of all vessels with a voyage on arc a.

In a similar way, the time-space network of a sub-graph $G_s\subset G$ is defined by a set of nodes $N_s=\{(i,t)\mid i\in V_s,\ t\in T\}$, and a set of travel arcs $A_s=\{((i,t_1),(j,t_2))\}$ such that $(i,j)\in E_s$, $t_1,t_2\in T$, and $t_2=t_1+\tau_{ij}^s$.

Let sets $\delta_s^+(n)$ and $\delta_s^-(n)$ represent a set of outgoing, and incoming travel arcs of a liner service $s\in S$. The shipping cost and vessel capacity for arc $a\in A_s$ that belongs to a service $s\in S$ are denoted as c_a^s and cap_a^s, respectively.

Let D be a set of customer demands for transportation in the service network. Each demand $d\in D$ is defined by the following parameters:

- q_d – certain quantity of containers to be shipped,
- FR_d – freight rate of maritime shipment,
- (o_d,b_d) – node-time pair, which specifies origin port, and beginning time of each container shipment d,
- (f_d,e_d) – node-time pair, which defines its destination and ending time.

Furthermore, the model assumes that not all demand must be satisfied, and thus, u_d denotes the number of containers rejected for transportation.

Since each transport demand has an origin and a destination with fixed departure and arrival time, it is reasonable to define the liner services that can fit customer orders. Such a definition will allow routing the cargo in sub-graphs instead of the whole services network. Therefore, let $S_d\in S$, be a set of services suitable for each shipping demand d.

The short-term leasing conditions are reflected by the following main parameters:

- Pick-up charges Pup_i in a port $i\in V$,
- Drop-off charges $Doff_i$ in a port $i\in V$,
- Leasing rate $rate_a$ for all containers traveling on arc $a\in A$,
- Leasing rate $LRate$ for a weekly time unit.

When containers are leased or returned back to a lessor the lift-on/off charges in leasing depots as well as the cost of container drayage to/from a port occur. These costs are reflected in the model by the parameter $Dray_i$ for each port $i \in V$. Additionally, the repair of leased containers might be needed before returning them to the lessor. As this cost can represent a significant number, it is also incorporated into the model through the parameter $Repair_i$, where $i \in V$.

The return of containers back to the leasing depots is restricted, and reflected by the following parameters:

- $RQuota$ – quota of containers that is allowed to be returned to the leasing company during each time interval $[l, l+\Delta)$, where $l \in TL$ and $TL \subset T$. The off-hire number is then calculated by applying the pre-defined quota to the total number of leased containers available at carrier's disposal at the beginning of a time interval.

- Q_i – certain port-related off-hire share, which limits the return of containers at each specific port $i \in V$ of the network.

The model also incorporates the requirement of the minimum average lease duration set by the lessors.

Furthermore, all leased containers available at carrier's disposal at the end of the planning horizon must be returned back to lessors. Thus, all these containers are the subject to the off-hire charges. A share w_h represents a portion of containers left at carrier's disposal in every time period beyond the planning horizon $h \in \{t_{\max}, \ldots, \infty\}$. The cost of keeping the leased containers in depots incorporates both storage and leasing rate and is denoted in the model as cw.

Finally, the cost of capital tied-up in leasing is defined based on an annual percentage rate r applied to the total cost of leased inventories for the period of weighted-averaged lease duration.

All decision variables in the model refer to the two main flows: the flow of full or empty containers owned by a shipping company. Hereafter, a list of such variables with related costs is presented.

$x_a^{d,s}$, $y_a^{d,s}$ – number of owned and leased containers, respectively, being used for a customer demand d on a link $a \in A_s$ that belongs to a service s;

x_a^0 , y_a^0 – number of empty owned and leased containers, respectively, being transported on a link $a \in A$;

$XT_{i,t}$, $YT_{i,t}$ – empty outflow of owned and leased containers, respectively, in a port i at a time t if the value is negative, and inflow – if positive; THC_i^0 and THC_i denote terminal handling charges for empty and loaded boxes, respectively, in a port i;
u_d – quantity of unsatisfied demand d;

$StX_{i,t}$, $StY_{i,t}$ – number of stored owned and leased containers, respectively, in a port i at a time t; StC_i and $StCap_i$ denote respective storage cost and storage capacity in a port i at a time t;

$YSL_{i,t}$, $YR_{i,t}$ – number of short-term leased containers and number of containers needing to be returned in a port i in a time t, respectively; $LCap$ denotes respective on-leasing capacity; $LTime$ denotes the required weighted average of lease duration;

$YLL_{i,t}$ – number of long-term leased containers in a port i in a time t; LLc_i denotes respective long-term leasing cost at a port i;

NL_l – number of leased containers at carrier's disposal at the beginning of interval $[l, l+\Delta)$;

The model is formulated as a multi-commodity network flow model, and presented as follows:

$$\max P = R - TC - HC - SC - STLC - STLC' - CC - LTLC \tag{4.1}$$

$$R = \sum_{d \in D} FR_d (q_d - u_d) \tag{4.2}$$

The objective function (4.1) maximizes the total profit from container management, calculated as the difference between revenue gained from loaded container transportation (4.2) and the costs associated with the container movements.

The costs consist of:

Transportation cost of empty and loaded containers,

$$TC = \sum_{d \in D} \sum_{s \in S_d} \sum_{a \in A_s} c_a^s (x_a^{d,s} + y_a^{d,s}) + \sum_{a \in A} c_a^0 (x_a^0 + y_a^0) \tag{4.3}$$

Handling cost,

$$HC = \sum_{d \in D} \sum_{i \in V | i = o_d} THC_i (q_d - u_d) + \sum_{d \in D} \sum_{i \in V | i = f_d} THC_i (q_d - u_d) + \sum_{(i,t) \in N} THC_i^0 (|XT_{i,t}| + |YT_{i,t}|) \tag{4.4}$$

Storage cost,

$$SC = \sum_{(i,t) \in N} StC_i (StX_{i,t} + StY_{i,t}) \tag{4.5}$$

Short-term leasing costs,

$$\begin{aligned} STLC = & \sum_{d \in D} \sum_{s \in S_d} \sum_{a \in A_a} rate_a y_a^{d,s} + \sum_{a \in A} rate_a y_a^0 + \sum_{(i,t) \in N} StY_{i,t} LRate \\ & + \sum_{(i,t) \in N} (Pup_i + Dray_i) YSL_{i,t} + \sum_{(i,t) \in N} (Doff_i + Dray_i + Repair_i) YR_{i,t} \end{aligned} \tag{4.6}$$

Cost of keeping the short-term leased containers beyond the planning horizon due to the return restrictions,

$$STLC' = \sum_{h=t_{\max}}^{\infty} NL_{t_{\max}} w_h cw, \quad t_{\max} \in T, \quad k \in \{t_{\max},\dots,\infty\} \tag{4.7}$$

Opportunity cost of capital tied up in leased inventory,

$$CC = (STLC + STLC')\left((1+r)^{\frac{LTime}{T}} - 1 \right) \tag{4.8}$$

Long-term leasing cost

$$LTLC = \sum_{(i,t)\in N} LLc_i YLL_{i,t} \tag{4.9}$$

The number of containers kept beyond the horizon in (4.7) is defined based on the total amount of leased containers at the end of the planning period and a portion of containers that will be left in depots after the return of allowed container quantity in each time interval.

Constraints:

$$\sum_{s\in S_d} \sum_{a\in\delta_s^+(n)} (x_a^{d,s} + y_a^{d,s}) = q_d - u_d, \quad \forall n = (o_d, b_d), \quad \forall d \in D \tag{4.10}$$

$$\sum_{s\in S_d} \sum_{a\in\delta_s^-(n)} x_a^{d,s} - \sum_{s\in S_d} \sum_{a\in\delta_s^+(n)} x_a^{d,s} = 0, \quad \forall n \in N \setminus \{(o_d,b_d),(f_d,e_d)\}, \quad \forall d \in D \tag{4.11}$$

$$\sum_{s\in S_d} \sum_{a\in\delta_s^-(n)} y_a^{d,s} - \sum_{s\in S_d} \sum_{a\in\delta_s^+(n)} y_a^{d,s} = 0, \quad \forall n \in N \setminus \{(o_d,b_d),(f_d,e_d)\}, \quad \forall d \in D \tag{4.12}$$

$$\sum_{s\in S_d} \sum_{a\in\delta_s^-(n)} (x_a^{d,s} + y_a^{d,s}) = q_d - u_d, \quad \forall n \in (f_d, e_d), \quad \forall d \in D \tag{4.13}$$

Constraints (4.10)-(4.13) are the network flow constraints that define a number of loaded leased and owned containers leaving their origin, going through the intermediate nodes, and arriving at their destination.

$$StX_{i,t} = StX_{i,t-1} - \sum_{d\in D} \sum_{s\in S_d} \sum_{a\in\delta_s^+(n)|n=(o_d,b_d)} x_a^{d,s} + \sum_{d\in D} \sum_{s\in S_d} \sum_{a\in\delta_s^-(n)|n=(f_d,e_d)} x_a^{d,s} + XT_{i,t} + YLL_{i,t}, \quad \forall n = (i,t) \in N \tag{4.14}$$

$$StY_{i,t}=StY_{i,t-1}-\sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^+(n)|n=(o_d,b_d)} y_a^{d,s}+\sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^-(n)|n=(f_d,e_d)} y_a^{d,s}+YT_{i,t}+YSL_{i,t} -YR_{i,t},\ \ \forall n=(i,t)\in N \tag{4.15}$$

Constraints (4.14) and (4.15) balance the container inventory flow, both own and leased ones.

$$XT_{i,t}=\sum_{a\in\delta^-(n)} x_a^0-\sum_{a\in\delta^+(n)} x_a^0,\ \ \forall n=(i,t)\in N \tag{4.16}$$

$$YT_{i,t}=\sum_{a\in\delta^-(n)} y_a^0-\sum_{a\in\delta^+(n)} y_a^0,\ \ \forall n=(i,t)\in N \tag{4.17}$$

Constraints (4.16) and (4.17) define a number of empty owned and leased containers that are being repositioned into and out of the ports.

$$NL_l=NL_{l-\Delta}-\sum_{(i,t)\in N|t\in[l-\Delta,l),\ l\geq\Delta} YR_{i,t}+\sum_{(i,t)\in N|t\in[l,l+\Delta)} YSL_{i,t},\ \ \forall l\in TL \tag{4.18}$$

Constraint (4.18) determines a number of all leased containers at a carrier's disposal at every time l. It is calculated as a sum of leased containers at carrier's disposal from the previous time interval $[l-\Delta,l)$ after returning the off-hire containers back to the lessor, and all new containers leased in the current time interval $[l,l+\Delta)$.

$$\sum_{t\in[l,l+\Delta)} YR_{i,t}\leq RQuota\cdot Q_i NL_l,\ \ \forall i\in V,\ \ \ \forall l\in TL\setminus\{t_{\max}\} \tag{4.19}$$

Constraint (4.19) restricts the return of leased containers in a port on a time interval $[l,l+\Delta)$.

$$YR_{it_{\max}}=Q_i NL_{t_{\max}},\ \ \forall i\in V \tag{4.20}$$

Constraint (4.20) ensures that all leased containers at the end of the horizon are destined for the return with or without additional keeping beforehand.

$$\sum_{d\in D}\sum_{s\in S_d}\sum_{a=((i,t_1),(j,t_2))\in A_s}\tau_{i,j}^s y_a^{d,s}+\sum_{a=((i,t_1),(j,t_2))\in A}\tau_{i,j}^0 y_a^0+\sum_{(i,t)\in N} StY_{i,t}\geq LTime\sum_{(i,t)\in N} YSL_{i,t} \tag{4.21}$$

Constraint (4.21) sets a minimum average lease duration weighted by a number of containers in different usage stage.

$$\sum_{(i,t)\in N} YSL_{i,t}\leq LCap \tag{4.22}$$

$$StX_{i,t}+StY_{i,t}\leq StCap_i,\ \ \forall(i,t)\in N \tag{4.23}$$

$$\sum_{d\in D}(x_a^{d,s}+y_a^{d,s})\leq cap_a^s,\ \ \forall a\in A_s,\ \ \forall s\in S \tag{4.24}$$

$$\sum_{d\in D}\sum_{s\in S_s|a\in A_s}(x_a^{d,s}+y_a^{d,s})+x_a^0+y_a^0\le cap_a^0,\ \ \forall a\in A \tag{4.25}$$

Constraint (4.22) limits a number of containers available for the short-term leasing over the planning period, and Constraint (4.23) restricts the storage capacity in each port of the network. Constraint (4.24) sets the boundary for the number of loaded leased and owned containers on arcs of a liner shipping service, and Constraint (4.25) limits the rest of the vessel capacity for empty container repositioning on a link.

$$x_a^{d,s},y_a^{d,s},x_a^0,y_a^0,u_d,XT_{i,t},YT_{i,t},StX_{i,t},StY_{i,t},YSL_{i,t},YR_{i,t},YLL_{i,t}\ge 0,\text{int} \tag{4.26}$$

Finally, Constraints (4.26) indicates that all decision variables can only take non-negative integer value.

4.4 Extension of the model though incorporation of container turn-around time in the region

4.4.1 Inland container trips in dynamic network flow presentation

This section describes a process of global container management, taking into account the travel time of containers in the inland regions. The model assumes that containers arriving to a port go to the inland region for unloading first, and only then return back to the port empty or reloaded with an export cargo. If there is a shortage of containers for the export shipment, empty containers must be repositioned into the ports and then sent into the inland region for export loading. In case of a weak export flow, the surplus of empty boxes is sent back to the port for global repositioning out of the area. Thus, an extra node for container inventory in an inland region is now added into the network, and the balancing of container flow is shifted from ports to the inland area.

The extended physical transport network is converted into the dynamic time-space network (Figure 4.2). A port and its corresponding inventory nodes in inland build a port's service area. Container inventory in inland is represented by two separate nodes for owned and leased equipment. Ports do not hold the container flow, but serve as entry or exit nodes for the inflow or outflow of the region.

In order to keep the presentation clear, Figure 4.2 illustrates a part of the whole network with only two ports *P*. These ports belong to the same region and have an intersection of their service areas. Lines from *P* to *O* in the service area of the same port represent a flow of owned loaded containers from a port to its inland area, while the reverse lines from *O* to *P* stand for the backhaul flow of empty (dashed lines) or loaded (straight lines) containers. Lines from *P* to *O* in the service areas of different ports represent owned containers that go from a port into the region and return to a different port. The redistribution of total regional container inflow between inland nodes $k\in I$ is modeled by the parameter α_k. It represents a portion of total import container flow in an inland node that will return empty or reloaded to the port that serves that inland area. Finally, the arcs between the same inland nodes in different time periods represent the storage of owned or leased container inventory in the port's inland area.

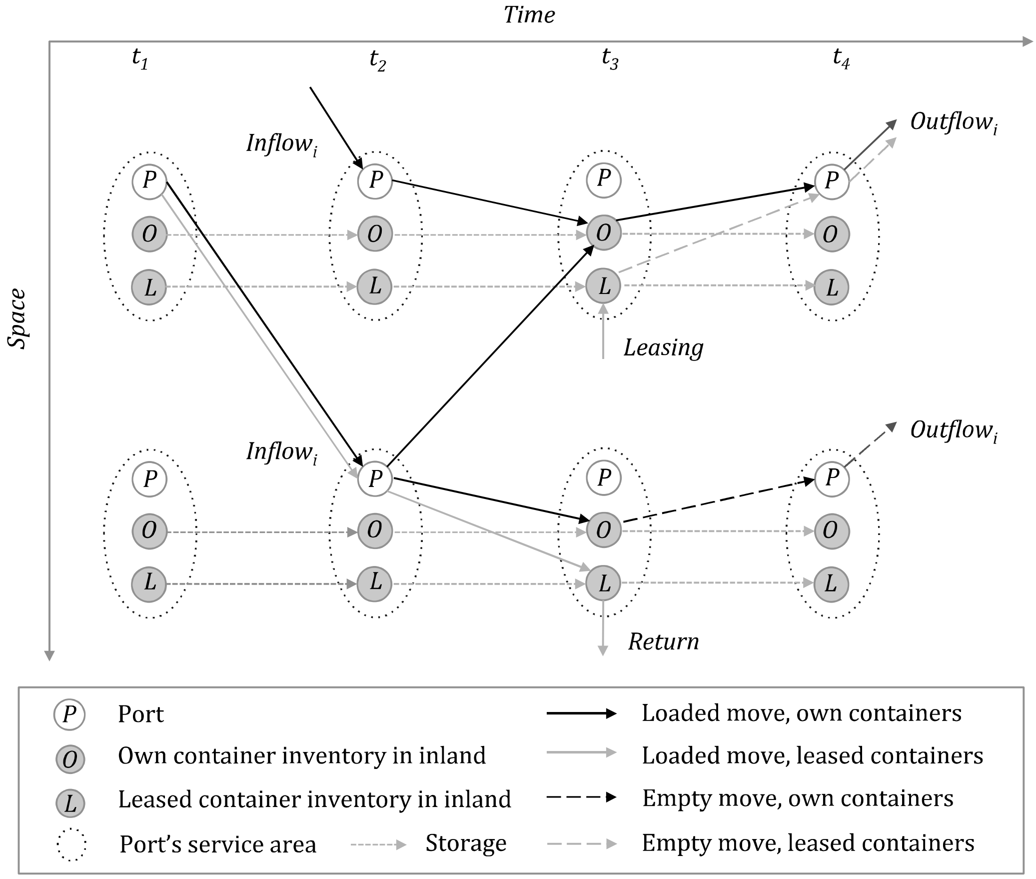


Figure 4.2: Container flow in a dynamic liner service network with consideration of turn-around time in the inland region

4.4.2 Mathematical formulation

This section explains additional notations needed for the extension of the Maritime Model with container turn-around time in inland regions.

All empty containers are moved in an aggregated network of liner services. An additional node $k \in I$, which represents an inland location served by a port, is added into the network as an extension of the previous formulation. Let $SA = \{i,k\}$ be an unordered port-inland pair, such that $i \in V$, $k \in I$ and $SA \in SAreas$. A weighted-average inland travel time from a port to an inland location and from that location to a port is defined by $\tau^0_{i,k}$ and $\tau^0_{k,i}$, respectively. Furthermore, all ports and inland nodes that belong to a certain region in the global shipping network (e.g. Europe, Asia, North America etc.) are grouped in sets V_R and I_R, respectively, where $R \in Regions$.

Having provided the notation in a physical network, the inland section of transport network is represented in a time and space by:

- $NI = \{(k,t) | k \in I, t \in T\}$ – set of inland nodes in a time,
- AI – set of inland travel arcs in a time-space presentation.

Each arc $a \in AI$ represents a combination of a port-time pair (i,t) and an inland-time pair (k,t) in a form $((i,t_1),(k,t_2))$ or $((k,t_1),(i,t_2))$, such that a port *i* and an inland node *k* belong to one service area, $i,k \in SA$, and $t_2 = t_1 + \tau^0_{i,k}$ or $t_2 = t_1 + \tau^0_{k,i}$, respectively.

Further on, all inland travel arcs originating at an inland node $m = (k,t) \in NI$ and all travel arcs ending at node m are listed in a set $\delta^+(m)$ and $\delta^-(m)$, respectively.

Transportation costs of all inland movements are not included into the model. However, each inland arc $a \in AI$ is associated with capital cost of containers cI for the time they spend in inland tI. Moreover, the movement of leased containers on an inland arc $a \in AI$ is additionally associated with leasing rate $rate_a$.

An aggregated maritime shipping network is represented by:

- Nodes $N = \{(i,t) | i \in I, t \in T\}$,
- Travel arcs $A = \{(i,t_1),(j,t_2) \mid (i,j) \in E,\, t_1,\, t_2 \in T,\, t_2 = t_1 + \tau 0_{ij}\}$, where T is a planning horizon.

All loaded containers are moved in the maritime network using one of the weekly liner services denoted by $s \in S$. Thereafter, the maritime arcs that belong to a specific liner service are grouped in a set $A^s = \{(i,t_1),(j,t_2) \mid (i,j) \in E^s,\, t_1,\, t_2 \in T,\, t_2 = t_1 + \tau^s_{ij}\}$.

Keeping the definition from the previous chapter, each customer demand $d \in D$ is characterized by:

- (o_d, b_d) – origin port and beginning time of a shipment,
- (f_d, e_d) – destination port and ending time of a shipments.

At the same time, in the extended model, the maritime shipments are added with container movement on an inland leg:

- An export container flow from the inland region to a port is defined as the total number of loaded containers leaving a port of origin in a time,
- An import container flow from a port into the inland region is defined as the total number of loaded containers arriving to a port of their destination in a time

Hereafter, a list of additional decision variables and parameters in the extended model is presented:

$x^{d,s}_a$, $y^{d,s}_a$ – number of owned and leased containers, respectively, being used for a customer demand d on an arc a of a service s;

x^0_a, y^0_a – number of empty owned and leased containers, respectively, being transported on a arc $a \in A \cup AI$; THC^0_k denotes terminal handling charges for empty boxes applied at an inland node $k \in I$, while THC_i defines handling charges in a port node $i \in V$;

$XI_{i,t}$, $YI_{i,t}$ – import owned and leased containers, respectively, arrived to a port i in a time t that will be sent into the inland region and will appear in the inland node in a weighted-average time tI_i; cI denotes capital cost of containers for the time they spend in inland;

$XE_{i,t}$, $YE_{i,t}$ – export owned and leased containers, respectively, that were sent from the inland node for the global shipping from a port i in time t;
u_d – quantity of unsatisfied demand d;

$StX_{k,t}$, $StY_{k,t}$ – number of owned and leased containers, respectively, stored in an inland node k in a time t; StC_k and $StCap_k$ denote respective storage cost and storage capacity in a port's inland area;

$YSL_{k,t}$, $YR_{k,t}$ – number of short-term leased containers and number of containers needing to be returned in an inland node k in a time t, respectively; $LCap$ denotes respective leasing capacity; $LTime$ denotes the required weighted average of lease duration;

$YLL_{k,t}$ – number of long-term leased containers in an inland node k in a time t; LLc_k denotes respective long-term leasing cost;

NL_l – number of leased containers at carrier's disposal at the beginning of the interval $[l, l+\Delta)$.

The previous model is adapted to incorporate the container turn-around in the inland regions, and presented as follows:

$$\max P = R - TC - IC - HC - SC - STLC - STLC' - CC - LTLC \tag{4.27}$$

$$R = \sum_{d \in D} FR_d (q_d - u_d) \tag{4.28}$$

The objective function (4.27) maximizes the total profit from container management, calculated as revenue gained from loaded container transportation (4.28) minus all associated costs.

$$TC = \sum_{d \in D} \sum_{s \in S_d} \sum_{a \in A_s} c_a^s (x_a^{d,s} + y_a^{d,s}) + \sum_{a \in A} c_a^0 (x_a^0 + y_a^0) \tag{4.29}$$

Transportation cost (4.29) only includes the cost of empty and loaded container movements between the ports.

$$IC = \sum_{(i,t) \in N} cI \cdot tI_i (XI_{i,t} + XE_{i,t}) + \sum_{a \in AI} cI \cdot tI_i x_a^0 \tag{4.30}$$

Inland costs (4.30), added in the extended model, represent the capital cost of loaded and empty containers for the time they spend in the inland region.

$$HC = \sum_{d \in D} \sum_{i \in V | i = o_d} THC_i (q_d - u_d) + \sum_{d \in D} \sum_{i \in V | i = f_d} THC_i (q_d - u_d) + \sum_{a \in \delta^-(k,t) | k \in I} THC_k^0 x_a^0 + \sum_{a \in \delta^+(k,t) | k \in I} THC_k^0 x_a^0 \quad (4.31)$$

Equation (4.31) calculates the handling cost. Handling charges are applied for loaded container flow in the origin/destination nodes, and for empty container inflow/outflow in the nodes of their entry or exit into or out of the inland region.

$$SC = \sum_{(k,t) \in NI} StC_k (StX_{k,t} + StY_{k,t}) \quad (4.32)$$

Storage cost (4.32) is calculated for inland nodes only.

$$STLC = \sum_{d \in D} \sum_{s \in S_d} \sum_{a \in A_s} rate_a y_a^{d,s} + \sum_{(i,t) \in N} LRate \cdot tI_i (YI_{i,t} + YE_{i,t}) + \sum_{a \in A \cup AI} rate_a y_a^0 + \sum_{(k,t) \in NI} StY_{k,t} LRate + \sum_{(k,t) \in NI} (Pup_k + Dray_k) YSL_{k,t} + \sum_{(k,t) \in NI} (Doff_k + Dray_k + Repair_k) YR_{k,t} \quad (4.33)$$

Short-term leasing cost (4.33) includes the leasing price for the time all loaded and empty containers spend in the inland region.

$$STLC' = \sum_{h = t_{\max}}^{\infty} NL_{t_{\max}} w_h cw, \quad t_{\max} \in T, \quad k \in \{t_{\max}, \dots, \infty\} \quad (4.34)$$

$$CC = (STLC + STLC') \left((1+r)^{\frac{LTime}{T}} - 1 \right) \quad (4.35)$$

$$LTLC = \sum_{(k,t) \in NI} LLc_k YLL_{k,t} \quad (4.36)$$

The rest of the cost components in the objective function (the cost of short-term leased containers kept beyond the planning horizon (4.34), the cost of capital tied up in leased inventory (4.35), and the long-term leasing cost (4.36)) are not changed.

Constraints:

$$\sum_{s \in S_d} \sum_{a \in \delta_s^+(n)} (x_a^{d,s} + y_a^{d,s}) = q_d - u_d, \quad \forall n = (o_d, b_d), \quad \forall d \in D \quad (4.37)$$

$$\sum_{s \in S_d} \sum_{a \in \delta_s^-(n)} x_a^{d,s} - \sum_{s \in S_d} \sum_{a \in \delta_s^+(n)} x_a^{d,s} = 0, \quad \forall n \in N \setminus \{(o_d, b_d), (f_d, e_d)\}, \quad \forall d \in D \quad (4.38)$$

$$\sum_{s\in S_d}\sum_{a\in\delta_s^-(n)} y_a^{d,s} - \sum_{s\in S_d}\sum_{a\in\delta_s^+(n)} y_a^{d,s} = 0, \quad \forall n\in N\setminus\{(o_d,b_d),(f_d,e_d)\}, \quad \forall d\in D \tag{4.39}$$

$$\sum_{s\in S_d}\sum_{a\in\delta_s^-(n)} (x_a^{d,s} + y_a^{d,s}) = q_d - u_d, \quad \forall n\in(f_d,e_d), \quad \forall d\in D \tag{4.40}$$

$$\begin{aligned} StX_{k,t} &= StX_{k,t-1} + \alpha_k \sum_{j\in V_R} XI_{j,t-tl_i} - XE_{i,t+tl_i} + \sum_{a\in\delta^-(k,t)} x_a^0 - \sum_{a\in\delta^+(k,t)} x_a^0 + YLL_{k,t}, \\ &\forall k\in I_R\cap SA, \quad \forall i\in V_R\cap SA, \quad \forall t\in T \end{aligned} \tag{4.41}$$

$$\begin{aligned} StY_{k,t} &= StY_{k,t-1} + \alpha_k \sum_{j\in V_R} YI_{j,t-tl_i} - YE_{i,t+tl_i} + \sum_{a\in\delta^-(k,t)} y_a^0 - \sum_{a\in\delta^+(k,t)} y_a^0 + YSL_{k,t} - YR_{k,t}, \\ &\forall k\in I_R\cap SA, \quad \forall i\in V_R\cap SA, \quad \forall t\in T \end{aligned} \tag{4.42}$$

Network flow constraints for import/export containers (4.37)-(4.40) stay without changes as well. However, inventory-balancing Constraints (4.41)-(4.42) are added for every inland node in a service area of its corresponding port located in a certain region. These constraints balance the total inflow of loaded and empty containers into the region with the total container outflow from the region. Since several ports may belong to the same global region, both Constraints (4.41) and (4.42) consider a share of total regional import flow in the inland node that will return empty or loaded to its corresponding port.

$$XI_{i,t} = \sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^-(n)} x_a^{d,s}, \quad \forall n=(i,t)\in N \tag{4.43}$$

$$YI_{i,t} = \sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^-(n)} y_a^{d,s}, \quad \forall n=(i,t)\in N \tag{4.44}$$

$$XE_{i,t} = \sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^+(n)} x_a^{d,s}, \quad \forall n=(i,t)\in N \tag{4.45}$$

$$YE_{i,t} = \sum_{d\in D}\sum_{s\in S_d}\sum_{a\in\delta_s^+(n)} y_a^{d,s}, \quad \forall n=(i,t)\in N \tag{4.46}$$

Constraints (4.43)-(4.44) define the inflow of import owned and leased containers into the inland region, respectively, while Constraints (4.45)-(4.46) calculate the outflow of export owned and leased containers from the inland region, respectively.

$$\sum_{a\in\delta^-(n)} x_a^0 - \sum_{a\in\delta^+(n)} x_a^0 = 0, \quad \forall n\in N\cup NI \tag{4.47}$$

$$\sum_{a\in\delta^-(n)} y_a^0 - \sum_{a\in\delta^+(n)} y_a^0 = 0, \quad \forall n\in N\cup NI \tag{4.48}$$

Constraints (4.47)-(4.48) forbid the storage of owned and leased containers in the ports.

$$NL_l = NL_{l-\Delta} - \sum_{(k,t)\in NI|\ t\in[l-\Delta,l),\ l\geq\Delta} YR_{k,t} + \sum_{(k,t)\in NI|\ t\in[l,l+\Delta)} YSL_{k,t}, \quad \forall l \in TL \tag{4.49}$$

$$\sum_{t\in[l,l+\Delta)} YR_{k,t} \leq RQuota \cdot Q_k NL_l, \quad \forall k \in V, \quad \forall l \in TL \setminus \{t_{\max}\} \tag{4.50}$$

$$YR_{k,t_{\max}} = Q_k NL_{t_{\max}}, \quad \forall k \in I \tag{4.51}$$

$$\begin{aligned}&\sum_{d\in D}\sum_{s\in S_d}\sum_{a=((i,t_1),(j,t_2))\in A_s} \tau^s_{i,j} y^{d,s}_a + \sum_{(i,t)\in N} tI_i (YI_{i,t} + YE_{i,t}) + \sum_{a=((i,t_1),(j,t_2))\in A\cup AI} \tau^0_{i,j} y^0_a \\ &+ \sum_{(k,t)\in NI} StY_{k,t} \geq LTime \sum_{(k,t)\in NI} YSL_{k,t}\end{aligned} \tag{4.52}$$

Constraints (4.49)-(4.51) are adopted from the previous model without any changes. Constraint (4.49) determines the number of all leased containers at a carrier's disposal at every time moment l, Constraint (4.50) restricts the return of leased containers in a port on a time interval $[l, l+\Delta)$, and Constraint (4.51) ensures that all leased containers at the end of the horizon will be destined for the off-hire with or without additional keeping beforehand. Lastly, Constraint (4.52) is adapted to integrate the inland travel time of loaded and empty containers into the minimum weighted average lease duration.

$$\sum_{(k,t)\in NI} YSL_{k,t} \leq LCap \tag{4.53}$$

$$StX_{k,t} + StY_{k,t} \leq StCap_k, \quad \forall (k,t) \in NI \tag{4.54}$$

$$\sum_{d\in D} (x^{d,s}_a + y^{d,s}_a) \leq cap^s_a, \quad \forall a \in A_s, \quad \forall s \in S \tag{4.55}$$

$$\sum_{d\in D}\sum_{s\in S_d | a\in A_s} (x^{d,s}_a + y^{d,s}_a) + x^0_a + y^0_a \leq cap^0_a, \quad \forall a \in A \cup AI \tag{4.56}$$

$$x^{d,s}_a, y^{d,s}_a, x^0_a, y^0_a, u_d, XI_{i,t}, YI_{i,t}, XE_{i,t}, YE_{i,t}, StX_{k,t}, StY_{k,t}, YSL_{k,t}, YR_{k,t}, YLL_{k,t} \geq 0 \tag{4.57}$$

The rest of the constraints are not changed. Constraint (4.53) limits a number of containers available for the short-term leasing over the planning period, and Constraint (4.54) restricts the storage capacity in each port of the network. Constraint (4.55) sets the boundary for the number of loaded leased and owned containers on arcs of a liner shipping service, and Constraint (4.56) limits the rest of the vessel capacity for empty container repositioning. Finally, Constraints (4.57) indicates that all decision variables are non-negative.

It must be noted that the extended model in the presented formulation can be solved only as a linear program (LP). The introduction of a portion α_k into Constraints (4.41)-(4.42) makes the model infeasible when forcing the integrality. In this case, in order to convert an optimal fractional solution of a relaxed problem into an approximately optimal integer solution, specific rounding heuristics and algorithms can be considered. For example, Brouer et al. (2011) present a simple rounding heuristic applied to the optimal LP solution of the proposed container management problem. All fractional variables are rounded down to ensure that capacity constraints are respected. At nodes with violated inter-balancing constraints, empty containers are added through the leasing variables in order to maintain feasibility. Such rounding heuristic provides a good integer solution in terms of the gap to the LP upper bound.

5 Optimization model II: Inland container management with an option of inland service restriction

5.1 Assumptions of the model

Loaded container movement: The model optimizes only empty ISO-container movements in the inland service network of an ocean carrier. The routing of loaded containers in the intermodal transport network represents a complex problem, which is typically treated separately from the empty container movements. Thus, the model assumes that all itineraries of inland shipments are calculated in advance. The corresponding transport costs, times, and tariffs are known in the model. Since import/export container movements are typically done as an intermodal shipment, the inland tariffs taken in the model include the price of a rail line haul and a round-trip truck drayage. The pick-up and drop-off of empty containers in the inland depots are being treated separately in the model.

Empty container movements: All movements that are being optimized in the model include container movements between depots and customer locations, empty container repositioning from inland depots back to the ports, and the possible repositioning between inland depots.

Assignment of customers to inland depots: Each depot supplies and collects empty containers for a customer cluster within its service area. At the same time, some customers are located in the service area of several depots and, therefore, having several options for the pick-up and drop-off of empty containers. Container trips are then differentiated by a premium to an inland tariff, which must be paid to a carrier in order to cover the cost of a longer truck drayage. Thus, the assignment of a customer to a more distant depot will lead to a higher tariff.

Street-turn movement: Direct exchange of empty boxes between import and export customers is allowed only when the customers are located in the same depot service area, and must be completed in less than a time unit. The street-turn is incorporated into the model through specific parameters adapted from Lei and Church (2011):

- Each import customer location has a portion of empty containers that can be transported directly to an export customer. This will create a street-turn from consignees.
- Each export customer location has a portion of container demand that can be met by direct transport from import customers. This will define a street-turn to shippers.

Empty container repositioning back to the port area: Total empty container surplus in the region is calculated for a certain trade route on a weekly basis as a difference between regional import and export on that route. The model assumes that an ocean carrier sets a certain time interval, within which all unused empty boxes must be returned back to the ports for the global repositioning. Moreover, in order to speed up the return of empty boxes to their shortage areas in the global network, the total turn-around of containers in the inland region is also restricted.

Empty container repositioning out of the inland region: The model assumes that the regional container surplus on a trade route must be shipped back globally to its corresponding shortage area (e.g. to Asia on the transpacific route, or to Europe on the transatlantic trade route). The repositioning out of the ports on a route can be done only at certain time periods, taking into account the frequency of vessel calls at a port within a week. Vessel capacity for repositioning out of a port on a route represents an aggregated value and equals the difference between import and export flow on a trade route, entering/leaving the region through a port. Thus, there is always an adequate capacity for empty containers.

Transport demand for inland haulage: The model assumes that an ocean carrier may limit its inland service network and choose not to satisfy all transport demand for inland pre- and end-haulages of cargo in the maritime containers. When an inland haulage is rejected, the carrier loses the customer on a whole shipping chain. As a result, an impact on a sea connection with a region is incorporated into the model through the following parameters: an average profit from a transport demand on the sea leg and an average cost for global empty container repositioning on a trade route. In addition, the rejection of an export transport demand frees an extra vessel capacity for the shipping from the corresponding port of export on a corresponding export trade route. At the same time, the number of empty repositioning out of the region is then added with additional containers.

Storage capacity: The model assumes limited storage capacity in the ports and inland depots.

Transport capacity: The model assumes unlimited transport capacity of the links in the network. The rail schedules are considered when creating the transport connections in the network.

5.2 Network flow presentation

The problem is presented as a dynamic network flow problem. The network consists of customer locations, inland depots, and ports. The links between nodes represent the movement of empty containers by truck or rail. It must be noted that different rail lines serve the whole rail transport network in North America. As a result, a rail movement of containers from one point to another may be characterised by an intermediate stop, where the transfer from one rail line to another takes place.

A possibility of rail-to-rail interchange is incorporated into the network through an extra link that represents additional cost and time of container transfer. Figure 5.1 depicts an example of an intermodal terminal with a junction of two rail lines. Nodes $T1$ and $T2$ represent a terminal as a part of rail network 1 and rail network 2, respectively. The link (*T*1,*T*2) illustrates an interchange between rail lines. Empty container pick-up or drop-off can be done at any node since both nodes represent the same terminal. Empty containers that will be shipped with rail line 1 are dropped off at the node *T*1, and containers that will be moved to a different direction with rail line 2 are dropped off at the node *T*2. Inventory balancing is done separately for each node. At the same time, the storage capacity is given for the whole terminal. Thus, a total number of container inventories in both nodes must be considered.

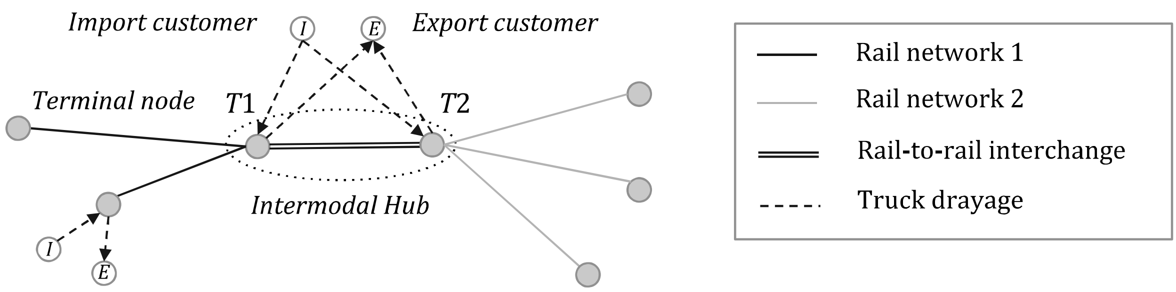


Figure 5.1: An example of transport network with a rail-rail interchange

A time-space network for dynamic container flow is defined by nodes in time. In order to keep the network presentation clear, Figure 5.2 illustrates only the representative links and container moves instead of the whole transport network with all range of container movements in it.

At a moment in time, it is known how many containers arrive to an import customer, how many containers are immediately unloaded and ready to be reused, and how many empty containers are requested from an export customer for a shipment. The links between customer locations and inland depots depict the drop-off and pick-up of empty boxes. Some of these movements might take time less than one time unit. Thus, certain links start and end in the same period. The links between customers represent the exchange with empty containers between them. This action must also be accomplished in the same time period.

Connections between different depots in different time units depict the inter-depot repositioning of empty containers to the shortage area, and connections between different depots in the same time unit describe the rail-to-rail interchange at a terminal. The interchange is available only in certain railway junctions, and all nodes connecting different rail lines together are grouped as one rail yard. Connections between the same depots in different time units represent the temporary storage of empty boxes before their reuse or return to the ports. Customers are not allowed to keep the emptied containers at their site. Therefore, there are no storage links for the customer locations.

Finally, the links from the inland depots to the ports depict repositioning of regional container surplus back to the port area. Empty containers are sent to the ports from inland depots only, using shuttle trains according to the schedule. At the same time, the outbound arrows from the ports represent a number of empty containers that must be repositioned out of the region globally. This number does not show an actual repositioning out of the ports but helps to account for an average repositioning cost from the region.

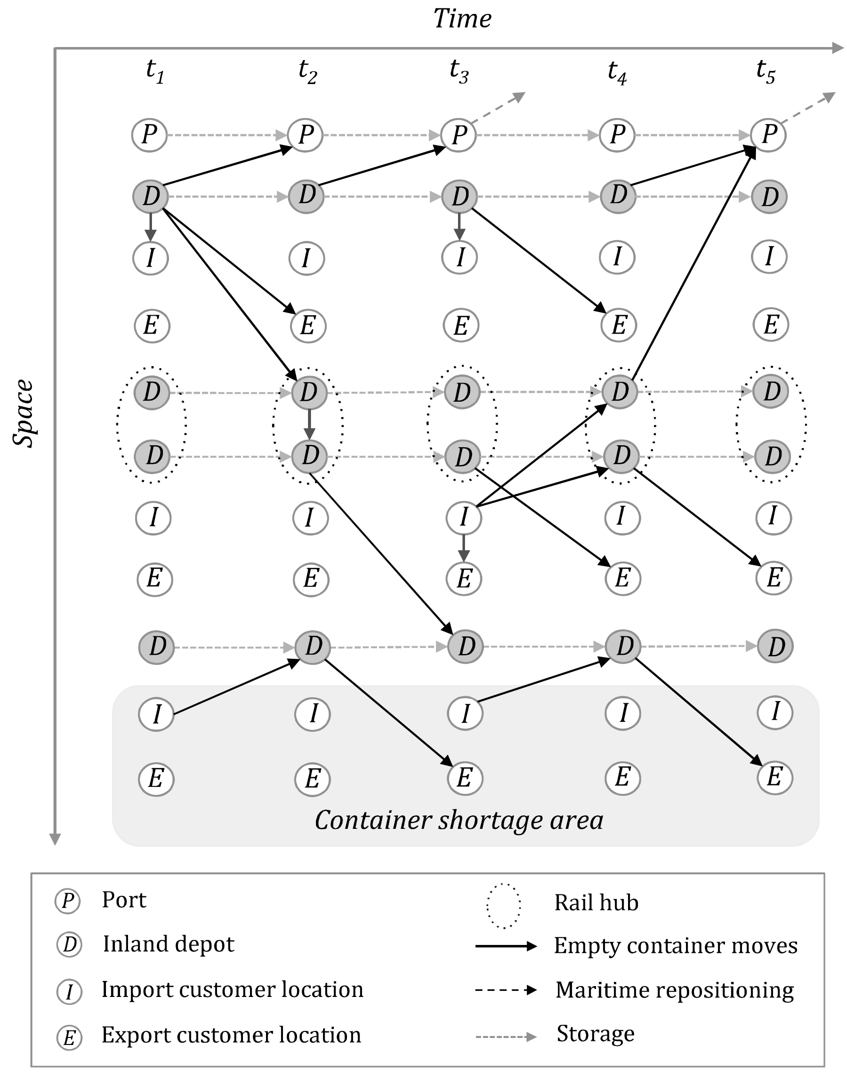


Figure 5.2: Dynamic container flow in an inland service network

5.3 Mathematical formulation

A physical network for inland container movements is represented by a directed graph $G=(V,E)$ with a set of nodes V, and a set of arcs E.

- Nodes include sets of import customer locations IM, export customer locations EX, inland depots $Depot$, and ports $Port$, so that $V = IM \cup EX \cup Depot \cup Port$.
- Set of arcs between nodes is presented as $E=\{(i,j) \mid i,j \in V, i \neq j\}$. Each arc $(i,j) \in E$ is associated with a certain travel distance τ_{ij}.

It must be noted that some depot-nodes represent a rail hub, where the interchange between different rail lines can be done. Therefore, such depot-nodes are grouped together, and the links between them depict an additional cost of the rail-rail transfer. Let $Depot_H$ denote a set of all depot-nodes that belong to a separate rail hub H, $H \in Hub$.

All depots and ports are characterized by the storage costs StC_k, where $k \in Port \cup Depot$. At

the same time, the storage capacity $StCap_k$ is defined only for a set of depots excluding those that belong to the rail hubs and that are involved into the rail interchange, $k \in Port \cup Depot - \bigcup_{H \in Hub} Depot_H$. All depots of a rail hub represent a single system and are are defined by a single storage capacity $StCapH_H$ of that rail hub, $H \in Hub$. Initial container inventory available in the inland depots at the beginning of the planning horizon is denoted by $StX_{k,0}$, $k \in Depot$.
The ports serve as exit gateway nodes for global empty container repositioning out of the region and thus are additionally characterized by the throughput capacity for the outbound empty container flow. Let $VCap^r_{p,t}$ be an aggregated vessel capacity for empty container repositioning out of a port $p \in Port$ in a time $t \in T$ on a trade route $r \in Route$, and ERc^r_p – a corresponding average repositioning cost.

In order to account for the dynamic decision process for a certain planning period $T = \{1,\ldots,t_{\max}\}$ the physical inland service network is converted into a time-space network with a set of nodes N and a set of arcs A:

- Each node $n \in N$ represents a node-time pair (i,t), where $i \in IM \cup EX \cup Depot \cup Port$, and $t \in T$.
- Each travel arc $a = ((i,t_1),(j,t_2)) \in A$ represents a combination of two nodes (i,t_1) and (j,t_2) such that $(i,j) \in E$, $t_1,t_2 \in T$ and $t_2 = t_1 + \tau_{ij}$.

Further on, all travel arcs originating at node n and all travel arcs ending at node n are listed in a set $\delta^+(n)$ and $\delta^-(n)$, respectively. The transportation cost of each arc $a \in A$ is denoted as c_a. Additionally, a certain premium to the inland tariff pr_a is assigned to an arc $a = ((i,t_1),(j,t_2))$ between customers and depots, $i \in IM, j \in Depot$ or $i \in Depot, j \in EX$. If a distance for the drop-off or pick-up of empty containers at a storage depot is higher than the one considered in an inland tariff, a premium takes a positive value, otherwise it equals zero.

For a given time horizon, an ocean carrier receives a set of demand for inland haulage of loaded containers from ports to import customers DI and a set of demand for inland haulage from export customers to ports DE. Each export demand $d \in DE$ has the following characteristics:

- $o_d \in EX$ – export customer location as an origin of export haulage;
- $b_d \in T$ – beginning time, when empty containers must be presented for loading at export customer site, and then hauled to a port for the ongoing sea shipping;
- $g_d \in Port$ – gateway port of the export shipment.

Correspondingly, each import demand $d \in DI$ is associated with:

- $f_d \in EX$ – import customer location as a destination of import haulage;
- $e_d \in T$ – ending time, when loaded containers arrive at customer site, emptied and are

ready for the reuse.

The rest of the parameters characterize both import and export demands $d \in DI \cup DE$:

- $tr_d \in Route$ – sea trade route associated with each inland shipment;
- tD_d – transport time of an inland haulage;
- q_d – a certain quantity of containers in each shipment;
- PRi_d and PRs_d – a certain profit obtained from a shipment on the inland- and sea-leg, respectively.

It must be noted that each customer cluster may have several shipping demands on different trade lines, routed through different domestic ports. Therefore, every customer order might represent a different profit value for an ocean carrier.

When import containers arrive at a customer location, they are immediately unloaded and are ready to be dropped off at an inland depot for the temporary storage. At the same time, a certain portion of empty containers may be exchanged directly between import and export customers without passing through the storage depots. In this case, in order to forbid the street-turn of empty containers between very distant customer locations, a depot service area is introduced. A depot service area defines the customers located within a service radius of a depot that can exchange empty containers.

Let IM_k and EX_k be the import and export customer locations, respectively, which belong to a service area of depot $k \in Depot$. The portion of empty containers that can be used for the street-turn from import customers or street turn to export customers is presented by the parameters α_i and β_i, respectively, where $i \in IM, j \in EX$. The street-turn cost STc is given as an average drayage cost, based on an average distance between import and export customer locations within a depot service area.

All decisions on empty container movements resulting from the inland import/export haulages are done for the daily time units. At the same time, the total regional demand for empty container repositioning out of the ports is calculated on a weekly time basis. Thus, a subset with weekly time moments is also introduced in the model as $TW = \{tw_1, tw_1 + \Delta, \ldots, t_{\max}\}$, where tw is assumed to be a first day of a week in a planning horizon, and Δ – weekly time interval, $TW \subset T$.

All empty containers must be returned back to the port area no later than in a fixed time tI. The total inland turn-around time of empty and loaded containers is limited by a certain value tIT.

Hereafter, a list of all decision variables with related parameters is presented.

x_a – number of empty containers repositioned on an arc $a \in A$ of an ocean carrier's inland service network;

$StX_{i,t}$ – number of empty containers stored in a node $i \in Depot \cup Port$ in a time t;

$STim_{i,t}$ – number of empty containers at an import customer location $i \in IM$ in a time t that can be sent directly to an export customer location;

$STex_{i,t}$ – number of empty containers that can be provided to an export customer location $i \in EX$ in a time t directly from an import customer;

$XR^r_{p,t}$ – number empty containers returned back to a port p in a time $t < tI$ for the ongoing sea shipment on a trade route r, where tI is a fixed inland travel time for empty containers that cannot be exceeded;

$Xout^r_{p,t}$ – number of empty containers that can be repositioned out of a port p in a time t on a global trade route r;

$VC^r_{p,t}$ – available vessel capacity for the global container repositioning out of a port p in a time t on a trade route r;

u_d – number of rejected demands for the inland haulage.

The model is formulated as a dynamic network flow model and can be presented as follows:

$$\max P = PR - ERCi - STC - SC - ERCs \tag{5.1}$$

$$PR = \sum_{d \in DI \cup DE} (PRs_d + PRi_d)(q_d - u_d) \tag{5.2}$$

The objective function (5.1) maximizes the total profit from container management in ocean carrier's inland service network considering the average profit from containers on sea legs. The total profit is calculated as average profit obtained from import/export containers on the sea- and inland-legs (5.2) minus all costs of empty container movements resulted from the loaded container shipments.

The costs consist of:

Cost of empty container repositioning in the inland region,

$$ECRi = \sum_{a \in A} x_a (c_a - pr_a) \tag{5.3}$$

Cost of street-turn movements,

$$STC = \sum_{(i,t) \in N | i \in IM \cup EX} STim_{i,t} STc \tag{5.4}$$

Storage cost in inland depots and ports,

$$SC = \sum_{(i,t) \in N | i \in Depot \cup Port} StX_{i,t} StC_i \tag{5.5}$$

Average cost of global empty container repositioning out of the ports,

$$ECRs = \sum_{r \in Route} \sum_{(p,t) \in N | p \in Port} XR_{p,t}^{r} ERc_{p}^{r} \tag{5.6}$$

Constraints:

$$\sum_{a \in \delta^{-}(i,t)} x_a = \sum_{d \in DI | i=f_d, t=e_d} (q_d - u_d) - STim_{i,t}, \quad \forall i \in IM, \quad \forall t \in T \tag{5.7}$$

$$\sum_{a \in \delta^{+}(i,t)} x_a = \sum_{d \in DE | i=o_d, t=b_d} (q_d - u_d) - STex_{i,t}, \quad \forall i \in EX, \quad \forall t \in T \tag{5.8}$$

Constraints (5.7) and (5.8) are the network flow constraints that define a number of empty container supply in each import customer location and an empty container demand at the export customer site, respectively.

$$q_d - u_d \geq 0, \quad \forall d \in DI \cup DE \tag{5.9}$$

Constraint (5.9) limits the number of rejected shipments for each particular demand.

$$STim_{i,t} \leq \sum_{d \in DI | i=f_d, t=e_d} \alpha_i (q_d - u_d), \quad \forall i \in IM, \quad \forall t \in T \tag{5.10}$$

$$STex_{i,t} \leq \sum_{d \in DE | i=o_d, t=b_d} \beta_i (q_d - u_d), \quad \forall i \in EX, \quad \forall t \in T \tag{5.11}$$

$$\sum_{i \in IM_k} STim_{i,t} = \sum_{j \in EX_k} STex_{j,t} \quad \forall k \in Depot, \quad \forall t \in T \tag{5.12}$$

$$\sum_{(i,t) \in N | i \in IM} STim_{i,t} = \sum_{(j,t) \in N | j \in EX} STex_{j,t} \tag{5.13}$$

Constraints (5.10) and (5.11) define a number of empty containers in the street-turn from import customers and in the street-turn to the export customers, respectively. At the same time, Constraint (5.12) puts a condition that the exchange of empty containers between the customers can only be done if they are located in the same depot service area; and Constraint (5.13) insures that the total number of empty containers sent from import customers equals the total number of empty containers received by export customers.

$$StX_{k,t} = StX_{k,t-1} + \sum_{a \in \delta^{-}(k,t)} x_a - \sum_{a \in \delta^{+}(k,t)} x_a, \quad \forall k \in Depot, \quad \forall t \in T \tag{5.14}$$

$$StX_{p,t} = StX_{p,t-1} + \sum_{a \in \delta^{-}(p,t)} x_a - \sum_{a \in \delta^{+}(p,t)} x_a - \sum_{r \in Route} Xout_{p,t}^{r}, \quad \forall p \in Port, \quad \forall t \in T \tag{5.15}$$

$$StX_{i,t} \le StCap_i, \quad \forall i \in Port \cup Depot - \bigcup_{H \in Hub} Depot_H, \quad \forall t \in T \tag{5.16}$$

$$\sum_{k \in Depot_H} StX_{k,t} \le StCapH_H, \quad \forall H \in Hub, \quad \forall t \in T \tag{5.17}$$

Constraints (5.14) and (5.15) are the inventory-balancing constraints, which enable to define a number of empty containers stored in depots and ports, respectively. The storage capacity of ports and single depots at rail yards is limited in Constraints (5.16). At the same time, the storage capacity of depots belonging to the intermodal hubs is limited separately for each hub in Constraint (5.17).

$$\sum_{t \in [tw, tw+\Delta]} \sum_{p \in Port} XR^r_{p,t+tI} = \sum_{d \in DI_d | tr_d = r, e_d \in [tw, tw+\Delta]} (q_d - u_d) - \sum_{d \in DE_d | tr_d = r, b_d \in [tw, tw+\Delta]} (q_d - u_d), \quad \forall r \in Route, \forall tw \in TW \tag{5.18}$$

Constraint (5.18) defines the total weekly number of empty container surplus in the inland region that must be returned back to the port area for the global repositioning on a specific trade route.

$$\sum_{a \in \delta^-(p,t)} x_a \ge \sum_{r \in Route} XR^r_{p,t}, \quad \forall p \in Port, \quad \forall t \in T \tag{5.19}$$

$$\sum_{a \in \delta^-(p,t) | p \in Port} x_a = \sum_{r \in Route} \sum_{(p,t) \in N | p \in Port} XR^r_{p,t} \tag{5.20}$$

Constraint (5.19) specifies that empty containers can be shipped from depots to the port's area at any time when the train connection is available, and Constraint (5.20) defines that the total volume of repositioning must equal the total demand in the ports. The vessel departure from the ports is, however, available only according the weekly schedule in certain time periods. Thus, Constraints (5.21) and (5.22) limit the number of empty containers that can be placed on the vessels for global repositioning on a specific route.

$$Xout^r_{p,t} \le \sum_{t_1 \in (tI,t)} XR^r_{p,t_1} - \sum_{t_1 \in (tI,t)} Xout^r_{p,t_1} \quad \forall p \in Port, \quad \forall t \in T, \quad t > tI, \quad \forall r \in Route \tag{5.21}$$

$$Xout^r_{p,t} \le VC^r_{p,t}, \quad \forall p \in Port, \quad \forall t \in T, \quad t > tI, \quad \forall r \in Route \tag{5.22}$$

$$VC^r_{p,t} = VCap^r_{p,t} + \sum_{d \in DE | g_d = p, tr_d = r, b_d + tD_d = t} u_d, \quad \forall p \in Port, \quad \forall t \in T, \quad \forall r \in Route \tag{5.23}$$

Constraint (5.21) defines that the outflow of empty containers from a port on a route must be less or equal to the total quantity of accumulated containers in the port if vessel capacity is adequate. The surplus of empty boxes in a port is calculated as a difference between the total empty container demand in a port until a time moment *t* and the total outflow from a port until the same time moment *t*. If vessel capacity is not adequate, the number of empty boxes accepted for global repositioning is equal to a maximum number of empty slots on a vessel as stated in Constraint (5.22). At the same time, a number of empty slots for repositioning can be increased as a result of export customer rejection. Therefore, Constraint (5.23) recalculates the value of available vessel capacity.

$$\sum_{d\in DI\cup DE} tD_d(q_d-u_d)+\sum_{(i,t)\in N|i\in IM} STim_{i,t}+\sum_{a=((i,t_1),(j,t_2))\in A}\tau_{i,j}x_a+\sum_{(k,t)\in N|k\in Depot} StX_{k,t}-\sum_{k\in Depot} t_{\max}StX_{k,0}\leq\sum_{d\in DI}(q_d-u_d)\cdot tIT \quad (5.24)$$

Constraint (5.24) set a restriction on a total inland turn-around time of all import containers that entered the region. It must be noted that the initial container inventory stored in inland depots over the planning period must be excluded from the total container volume in the region.

$$x_a, StX_{i,t}, STim_{i,t}, STex_{i,t}, XR^r_{p,t}, Xout^r_{p,t}, VC^r_{p,t}, u_d \geq 0, \text{int} \quad (5.25)$$

Finally, Constraint (5.25) indicates that all decision variables take non-negative integer value.

6 Case study for the maritime container management

6.1 Network of the case study

6.1.1 Network of liner services

The case study focuses on the main trade routes: Transpacific, Transatlantic and North Europe–Far East. The size of the physical network is limited to the major ports in each trade region (Table 6.1).

Table 6.1: Ports of the global shipping network

Trade region	Ports	Nodes in physical network
North Europe	Hamburg	HAM
North America:		
East Coast (ECNA)	New York	NY
	Savannah	SAV
West Coast (WCNA)	Los Angeles	LA
	Vancouver	VAN
Far East:		
South-East Asia	Singapore	SIN
China	Shanghai	SHG
	Hong Kong	HK
North Asia	Tokyo	TOK

The weekly liner services are chosen based on the transport network of Hapag-Lloyd, which is publicly available on the company's website (Hapag-Lloyd, 2012). The services are then put together into 6 main groups:

- North Europe–Asia (EA),
- Transpacific from WCNA (TPw),

- Transpacific from ECNA (TPe),
- Transatlantic (TA),
- North Europe–North America–Asia via Panama Canal (EAA),
- North America–Asia via Suez Canal (AA).

Each group of aggregated services represents a typical shipping route in the global network and can be viewed as a sub-network (Figure 6.1).

The shipping time between ports is defined from the publicly available resources of Hapag-Lloyd (Hapag-Lloyd, 2012) and is presented in days. The time in days is converted into weeks by dividing its value by 7 with rounding to the nearest integer. Certain values are, rounded up in order to keep the consistency with other services in a group. Furthermore, the shipping time between specific ports is set to 0 since it makes up less than 4 days: e.g. the travel time between Shanghai and Hong Kong, or New York and Savannah. The transport cost is still applied to such links and is calculated based on the transport time given in days.

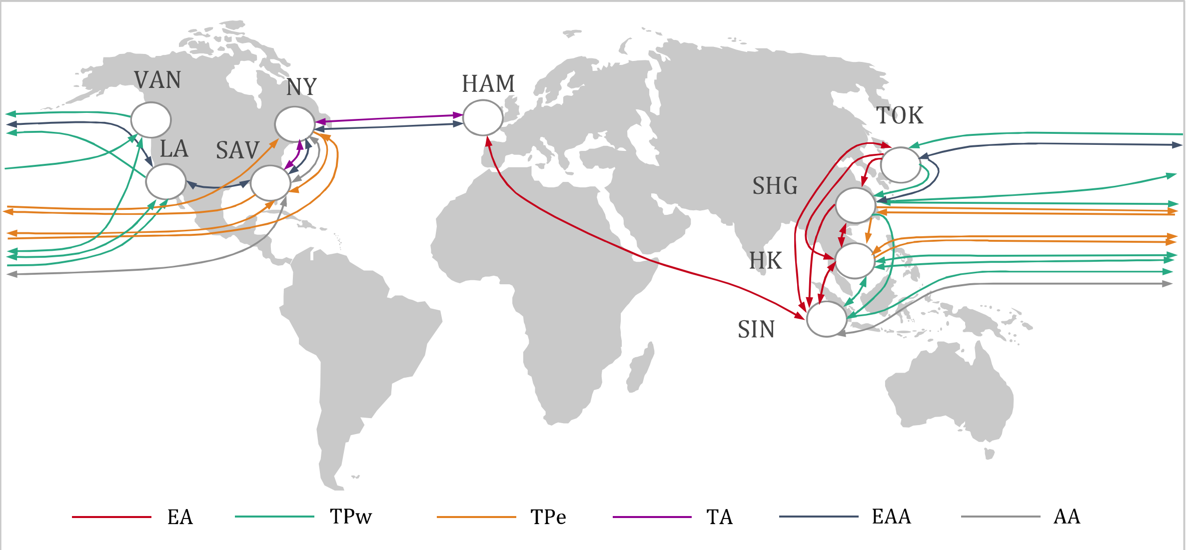


Figure 6.1: Unaggregated shipping network with 6 liner services

All liner services with shipping time between ports are presented in Appendix A Table A.1.

Finally, an average vessel size on each aggregated service (see Table 6.2.) is set based on the analysis of vessel deployment on the main trade routes (MDS Transmodal, 2009; Devidson, 2014).

Table 6.2: Size of container ship on aggregated liner services

Aggregated service	**Vessel size (TEU)**	**Assumed vessel size (TEU)**
EA	> 9000	9000
TPw	8000 – 9000 4000 – 5000	7650*
TPe	4000 – 5000	5000
TA	2000 – 3000	3000
EAA	5000 – 6000	5000
AA	5000 – 6000	6000

* Calculated as weighted-average value

It must be noted that the transpacific route is characterized by 2 typical sizes of vessel: with a range of 4000 – 5000 TEUs and over 8000 TEUs. As a result, the case study assumes that this route has an average size of the container ship, weighted by the total container volume carried on each vessel type.

6.1.2 Aggregation of dynamic shipping network

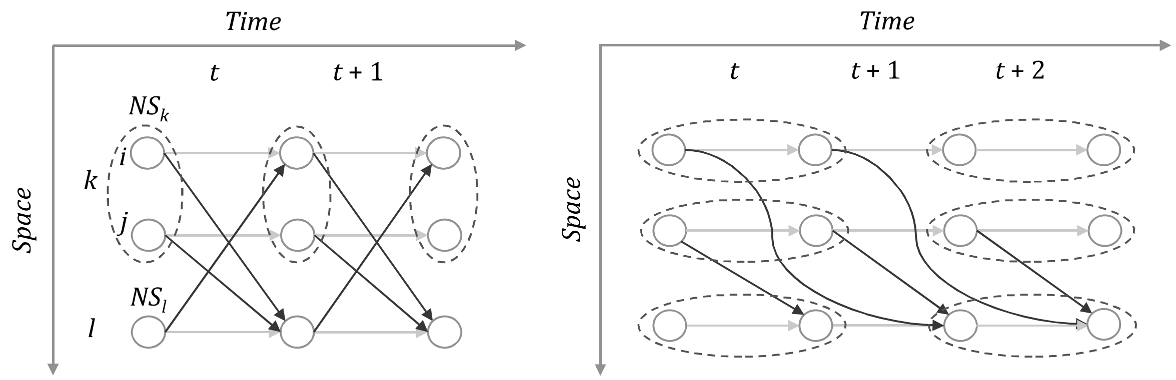
Theoretical foundation for network aggregation: The physical shipping network presented above is converted into the time-expanded network. Due to the much larger scale of the dynamic shipping network, the solving process of the model becomes much more time-expensive. In this case, the application of network aggregation methods can reduce the size of large-scale linear or integer programs.

Almost all aggregation approaches imply the following procedure (Dreifus, 2005, p. 38):

- Construct an aggregated problem (AP) to the original unaggregated problem (UAP);
- Solve the AP;
- Disaggregate an optimal or a feasible solution of the AP into solution for the original problem;
- If optimality is required – use the derived solution as an initial solution for the UAP, which is then iteratively improved to optimality;
- If no optimal solution is required – use the derived solution as a feasible solution for the UAP, determine bounds on the error and evaluate the result.

When constructing the AP in the dynamic network, two dimensions for aggregation can be distinguished: horizontal, which corresponds to time, and vertical, which corresponds to space (Figure 6.2).

- The horizontal aggregation reduces only the time units by combining the smaller time periods into the larger ones.
- The vertical aggregation consolidates specific nodes together.



a) Vertical aggregation a) Horizontal aggregation

Figure 6.2: Vertical and horizontal dimensions of network aggregation

Since the shipping network in the given case study contains the ports that are located very close to each other, and the travel arcs between them have zero transportation time, the consolidation of nodes is chosen.

It must be noted that when grouping the nodes in the dynamic shipping network, the following requirements must be satisfied (Dreifus, 2005, pp. 104-105):

- Two nodes $i(t)$ and $j(t')$ are grouped together if they are located in the same time period, $t = t'$.
- Two nodes $i(t)$ and $j(t)$ are grouped together if the same nodes from the previous or following periods are grouped together (see Figure 6.2a).

The aggregation in the vertical dimension changes the sets of nodes and arcs in the network. Therefore, it requires the recalculation or respecification of cost parameters, transport capacities, and shipping demand in the aggregated network flow problem. Depending on the type of respecification map, the following two main methods of aggregation can be distinguished:

- Aggregation by dominance introduced by Balas (Balas, 1965; Francis, 1985)
- Weighted aggregation suggested by Zipkin (Zipkin, 1975; Zipkin, 1980)

Before explaining the methods, the notation to the network flow problem must be provided. Let an aggregated dynamic network flow problem with consolidated nodes (ANFP) has the following formal formulation:

$$\min_{\bar{x} \in \bar{X}} \sum_{t \in T} \sum_{(k,l) \in \bar{A}} \bar{c}_{kl}(t) \bar{x}_{kl}(t)$$

s.t.

$$\sum_{k:\,(k,l) \in \bar{A}} \bar{x}_{kl}(t-1) - \sum_{k:\,(l,k) \in \bar{A}} \bar{x}_{lk}(t) = \bar{b}_k(t), \quad \forall k \in \bar{N}, \quad \forall t \in T$$

$$0 \le \bar{x}_{kl}(t) \le \bar{u}_{kl}(t), \qquad \forall (k,l) \in \bar{A}, \quad \forall t \in T$$

where:

$\bar{N}$ – set of aggregated nodes. Each aggregated node represents a subset of combined nodes $NS_k = \{i:\, i \in N\}$ in the original unaggregated network, $NS_k \subseteq N$, and is defined as k in the derived aggregated network (Figure 6.2a).

$\bar{A}$ – set of aggregated arcs (k,l), where $k,l \in \bar{N}$, $k \ne l$.

T – planning horizon with time periods $t \in T$.

$\bar{x}_{kl}(t)$ – flow on an aggregated arc (k,l) at a time period *t*.

$\bar{c}_{kl}(t)$, $\bar{u}_{kl}(t)$ – shipping cost and capacity, respectively, of an arc (k,l).

$\bar{b}_k(t)$ – supply at an aggregated node k at a time period *t*, if positive value, or demand, if negative value. If $\bar{b}_k(t) = 0$, the node k is an intermediate node.

Aggregation by dominance implies the recalculation of cost parameter of an aggregated arc as a minimum over all costs of original arcs that are being aggregated.

$$\bar{c}_{kl}(t) = \min_{(i,j)\in A:\, i\in NS_k,\, j\in NS_l} c_{ij}(t), \qquad \forall (k,l)\in \bar{A},\ \forall t\in T$$

The capacity of an aggregated arc is redefined as a sum of all capacities of combined original arcs while supply/demand of an aggregated node represents the sum of all supply/demand of consolidated original nodes.

$$\bar{u}_{kl}(t) = \sum_{(i,j)\in A:\, i\in NS_k,\, j\in NS_l} u_{ij}(t), \qquad \forall (k,l)\in \bar{A},\ \forall t\in T$$

$$\bar{b}_k(t) = \sum_{i\in NS_k} b_i(t), \qquad \forall k\in \bar{N},\ \forall t\in T$$

Presented respecification map makes the ANFP a relaxed version of the original problem, which yields an approximate objective value and a feasible solution with a certain bound on error for the original unaggregated problem.

Weighted aggregation implies a convex combination for recalculation of costs and capacities in the aggregated network by using the weights of arcs that are consolidated in the original problem.

$$\bar{c}_{kl}(t) = \sum_{i\in NS_k} \sum_{j\in NS_l} w_{ij}^{kl}(t) c_{ij}(t), \qquad \forall (k,l)\in \bar{A},\ \forall t\in T$$

$$\bar{u}_{kl}(t) = \min_{(i,j)\in A:\, i\in NS_k,\, j\in NS_l} \{\frac{u_{ij}(t)}{w_{ij}^{kl}(t)} : w_{ij}^{kl}(t) > 0\}, \qquad \forall (k,l)\in \bar{A},\ \forall t\in T$$

$$\bar{b}_k(t) = \sum_{i\in NS_k} b_i(t), \qquad \forall k\in \bar{N},\ \forall t\in T$$

where:

$$w_{ij}^{kl}(t) = w_i^k(t) w_j^l(t), \qquad \forall i\in NS_k,\ \forall j\in NS_l,\ \forall (k,l)\in \bar{A},\ \forall t\in T$$

$$w_i^k(t) = \begin{cases} \dfrac{|b_i(t)|}{\bar{b}_k(t)}, & b_i(t)\neq 0, \qquad \forall i\in NS_k,\ \forall k\in \bar{N},\ \forall t\in T \\ w_i^k(t)\in[0,1], & b_i(t) = 0 \quad \text{s.t.} \sum_{i\in NS_k} w_i^k(t) = 1, \qquad \forall i\in NS_k,\ \forall k\in \bar{N},\ \forall t\in T \end{cases}$$

The presented respecification map requires more efforts to define the costs and capacities in the ANFP, and leads to the non-integer solution. Moreover, the definition of capacities sets a tighter limit, which might lead to the infeasibility of the derived problem. Finally, a set of assumptions must also be satisfied when grouping the nodes: e.g. supply, demand, or intermediate nodes must be aggregated separately. Furthermore, the combined nodes must have the same incoming and outgoing arcs. These assumptions make the application of weighted aggregation method to the real-world networks quite restrictive.

Aggregation of the shipping network in the case study: Because the application of the weighted aggregation method to the dynamic shipping network in the given case study is fairly difficult, the vertical aggregation by dominance is chosen. Only the ports on the West Coast and the ports on the East Coast of North America are consolidated (Figure 6.3). The ports on the same coast have similar terminal handling charges, drop-off fees, and storage costs (see Table 6.7), which makes the aggregation easier. The ports in the Asian region are more distinct from each other. As a result, they are left in the network unaggregated even though the transportation time between some of the ports is equal to zero.

Table 6.3: Ports of the aggregated shipping network

Trade region	Ports	Nodes in original network	Nodes in aggregated network
North Europe	Hamburg	HAM	EU
ECNA	New York Savannah	NY SAV	ECNA
WCNA	Los Angeles Vancouver	LA VAN	WCNA
Asia	Singapore Shanghai Hong Kong Tokyo	SIN SHG HK TOK	SIN SHG HK TOK

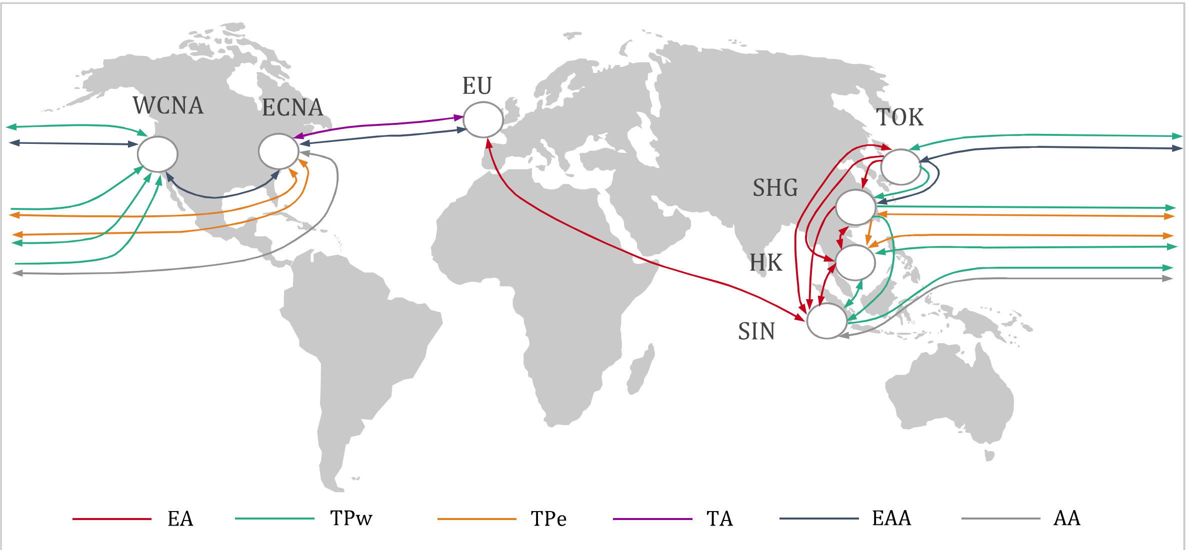


Figure 6.3: Aggregated shipping network with 6 liner services

For clarity reasons, the derived network in Figure 6.3 is only shown in the static presentation. In the dynamic presentation, every node and arc are repeated in time over the whole planning horizon.

The solution derived from the optimization in the aggregated shipping network is presented further without disaggregation and is used as a feasible solution for the relaxed original problem.

6.1.3 Container traffic and container fleet

There are no detailed statistics for the traffic volume between a particular pair of ports. As a result, these data are estimated based on different trade statistics and a certain calculation approach used in Imai et al. (2009). The authors model the traffic volumes for each port-pair taking into consideration an actual vessel capacity deployed on a service line, an average load factor of the vessel, and the traffic imbalance rate on a route. All data for the current case study is taken for the year 2010. The comparison of the distribution of the calculated container flow with the statistical data shows the correspondence with the real-world conditions (Appendix A Table A.4). The following section describes the estimation procedure in more details.

Container traffic: The planning horizon in the case study is set to 1 year, divided into 52 time intervals, where each interval represents a week. The customer demand for shipping is, correspondingly, generated for each week.

Total weekly transport demand between a pair of unaggregated ports is estimated in 3 steps based on the approach described in Imani et al. (2009). The following assumptions are made:

- Weekly container flow on a liner service on the headhaul/backhaul equals the vessel capacity on this line, applied with the load factor 0.85 and corrected with the imbalance ratio on the trade route.
- Container flow on a vessel is then distributed between each separate port in the origin and the destination region based on its transshipment share.
- Total weekly container volume between a pair of origin and destination ports is calculated as a sum of container shipments for a given pair of ports on all vessels.

$$g_{ij} = \sum_{s \in S} q^s LF \cdot imb \cdot T_i^s T_j^s \ ,$$

where:

q^s – vessel capacity deployed on a service line s;

LF – load factor of the vessel;

imb – imbalance ratio on a trade route;

T_i^s, T_j^s – transshipment share of a port in origin region and a port in destination region, respectively, on a service line s: e.g. transshipment share of Shanghai in a set of Asian ports or transshipment share of Hamburg in a set of European ports on the service line “Loop 4” (Hamburg – Singapore – Shanghai – Singapore – Hamburg).

Transshipment share of a port is defined separately for each service line s as follows:

$$T_i^s = \frac{Q_i}{\sum_{i \in PortO^s} Q_i} \ ,$$

where Q_i – transshipment volume in a port i from a set of ports in origin region $PortO^s$ on a service s: e.g. a set of Asian ports on the westbound direction of a service line "Loop 4". If a port belongs to the destination region, a corresponding set of ports $PortD^s$ is then used in the formula.

The data and the resulted distribution of weekly container traffic in the unaggregated network are presented in Appendix I. The shipping orders in the aggregated ports are then summarized, and the derived results are shown in Table 6.4.

The case study assumes the total weekly container traffic of 100000 TEUs. Then, the annual traffic results in 5200000 TEUs.

Container fleet: Total container inventory of an ocean carrier is set using Container Traffic to Container Fleet (Traffic/Fleet) ratio. According to container supply review performed by World Shipping Council, the global Traffic/Fleet ratio was between 5 and 6 for 2010 (World Shipping Council, 2015, p. 6). This ratio for individual carriers may be affected by numerous factors: e.g. type of the trade route (long-haul trade or short-haul trade), the imbalance rate, etc. At the same time, the tendency of changes in the carrier's container inventory is still correlated with the global situation. As a result, the Traffic/Fleet ratio in the case study is varying from 5 to 6 depending on a scenario.

At the beginning of the planning horizon, in the time period t = 0, container inventory is presented in the aggregated ports according to port's export volume (see Table 6.4). Container shipments arriving at the ports from the previous planning period are also added to the total inventory.

Table 6.4: Distribution of weekly container traffic in the aggregated shipping network (%)

Ports	EU	ECNA	WCNA	TOK	SIN	SHG	HK	Export	Import
EU	–	5.1	1.3	0.3	5.0	2.8	2.5	17	25
ECNA	3.7	–	–	0.1	1.9	3.5	2.6	12	18
WCNA	0.9	–	–	2.1	3.0	6.3	2.9	15	24
TOK	0.3	1.3	3.8	–	–	–	–	5	3
SIN	9.6	3.1	9.2	–	–	–	–	22	10
SHG	5.5	4.4	7.2	–	–	–	–	17	13
HK	4.8	4.1	2.6	–	–	–	–	11	8

6.1.4 Freight rates

Freight rates for container shipping in the given service network are based on the average All-in rates presented for the main trade routes in the publicly available resources. These rates can be used in the case study since they include all main and additional fees related to the transportation. For example, apart from actual shipping and handling costs, All-in rates also include BAF[2], CAF[3], etc.

[2] BAF – Bunker Adjustment Facto;
[3] CAF – Currency Adjustment Factor.

It must also be noted that the freight rates are presented for the trade regions and not for the specific ports. Thus, all ports in Asia and on the West/East Coast of North America have equal rates in the case study (Table 6.5). Moreover, the rates between West Coast of North America and Europe (EU-WCNA) are rarely available in the literature. As a result, these rates are estimated based on the rates for the ECNA-Europe connection using the adjustment factor. The factor is calculated as a ratio of the freight rates for WCNA-Asia and ECNA-Asia. It equals 1.45 for eastbound direction and 1.74 for westbound direction.

Table 6.5: Freight rates in the aggregated shipping network in 2010 ($/TEU)

	Region	Europe	ECNA	WCNA	Asia			
Region	**Ports**	**EU**	**ECNA**	**WCNA**	**TOK**	**SIN**	**SHG**	**HK**
Europe	**EU**	–	2296	3323*	923	923	923	923
ECNA	**ECNA**	1255	–	–	1673	1673	1673	1673
WCNA	**WCNA**	2185*	–	–	961	961	961	961
Asia	**TOK**	2179	2964	2048	–	–	–	–
	SIN	2179	2964	2048	–	–	–	–
	SHG	2179	2964	2048	–	–	–	–
	HK	2179	2964	2048	–	–	–	–

* Own estimation.
Source: Drewry Research (2011), p. 51

6.1.5 Costs

Shipping cost: Shipping cost includes daily fixed cost per TEU and daily variable cost per TEU, which are estimated for different vessel sizes in Schönknecht (2007). The value of parameters is adjusted from the year 2005 to 2010 using an average global inflation rate of 1.7% p.a. (Wirtschaftskammer Österreich, 2015) and converted from Euro into US dollars with an average exchange rate of 1.3339 for 2010 (Oanda, 2015). It must be noted that the resulted total daily shipping cost per TEU (Table 6.6) does not include the canal cost, which simplifies the cost calculations in the model.

The data of daily shipping costs are then used to define the cost of arcs in a sub-network of each liner service. At the same time, the network for empty container repositioning consolidates all liner services. In this case, the cost of an aggregated arc is defined as a minimum over the costs of all liner services with a voyage on this arc. The time and cost data are summarized in Appendix A Table A.6.

Table 6.6: Daily shipping cost for different vessel size in 2010 ($/TEU)

Aggregated service	**Vessel size in TEU**	**Fixed cost**	**Variable cost**	**Total cost**
EA	> 9000	14.62	11.80	26.41
TPw	8000 – 9000 4000 – 5000	14.83 17.37	12.00 10.16	27.10*
TPe	4000 – 5000	17.37	10.16	27.53
TA	2000 – 3000	19.90	10.75	30.65
EAA	5000 – 6000	16.64	15.43	32.07
AA	5000 – 6000	16.64	15.43	32.07

* Calculated as weighted-average for two vessel types: 5000 TEU and 9000 TEU.

Handling cost: It is fairly difficult to estimate the value of handling charges because each ocean carrier can negotiate this price with terminal operators according to its average handling volumes as well as different business model. However, it is possible to use Terminal Handling Charges (THC) as a basis (Schönknecht, 2007, p. 66). Ocean carriers present these charges to the customers for loading and unloading of containers in the ports. The case study assumes that 80% of these charges are paid to the terminal operators as a port due.

The handling cost in different ports is converted from the local currency to US dollars using an average exchange rate for 2010 (Table 6.7). All ports that are being aggregated together have equal costs.

Storage cost: The storage cost in different ports is set for the year 2010 according to the data provided by the leasing companies (Abram, 2012, p. 87) and presented for a weekly time unit in Table 6.7.

Leasing cost: All components of the leasing cost such as pick-up, drop-off charges, and per diem rates are estimated for the year 2010 based on the interviews with the leasing companies (Abram, 2012, p. 85). The pick-up and drop-off charges do not vary for long-term and short-term leasing options. Moreover, the leasing companies typically do not apply the pick-up charges in selected ports of the case study. However, in any case, the cost of empty container haulage from/to the leasing depot is still incurred.

- Per diem rate for short-term leasing is $1.15 per day per TEU.
- Per diem rate for long-term leasing is $0.95 per day per TEU (Abram, 2012, p. 85).
- Drop-off charges are summarized in Table 6.7.
- The drayage cost is estimated to be around $50 per TEU, assuming that the leasing depots are located in the proximity of terminals (under 10 miles), and the trucking cost ranges around $2/miles in 2010 (TransCore, 2011).
- Repair cost is assumed to be minimally $100 per TEU (Boile, 2006, p. 66; experts' opinion).

Table 6.7: Selected charges in ports of the unaggregated shipping network in 2010

Port	THC (local currency/TEU)		THC ($/TEU)	Storage cost ($/TEU/day)	Storage cost ($/TEU/week)	Drop-off charges ($/TEU)
NAM	210	Euro	250.89	0.5	3.5	175
NY	420	US$	378.00	0.7	4.9	550
SAV	420	US$	378.00	0.7	4.9	550
LA	420	US$	378.00	0.7	4.9	450
VAN	420	US$	378.00	0.7	4.9	450
SIN	190	SGD	139.45	0.35	2.45	0
SHG	460	CNY	67.87	0.35	2.45	0
HK	2065	HKD	265.79	0.35	2.45	0
TOK	21000	JPY	239.61	1.2	8.4	0

Source: THC – Hapag-Lloyd (2012); Storage, drop-off costs – Abram (2012), pp. 85-87

Cost of capital: The percentage rate for the cost of capital tied up in leased inventory is set to 10% p.a. based on the estimated cost of capital in the global transportation industry in 2010

(Damoradan, 2011) as well as data from other studies (Maloni et al., 2013; Saldanha et al., 2009)

6.1.6 Capacities and quotas

Capacity of the travel arcs in the network: Vessel capacity on service lines (see Table 6.2) is adapted to the weekly container volume of 100,000 TEU used in the case study. The load factor for vessels remains to be 0.85, but considering the imbalance rate, it results in an average number of 0.7. As a result around 30% of vessel capacity is available for empty container repositioning on the backhauls to Asia.

The capacity of a travel arc in a sub-network of aggregated liner services is calculated as an accumulated capacity of all vessels with a voyage on a given arc. At the same time, the capacity of a travel arc in the network for empty containers represents the sum of capacities of respective aggregated arcs. These data are presented in Appendix A Table A.7.

Capacity of storage depots: It is assumed that the storage capacity in a port depot *i* is correlated to the port's export share, and the total capacity is limited to 70% of all carrier's container inventory:

$$StCap_i = TotalInventory \cdot ExportShare_i \cdot 0.7$$

Thus, the storage capacity is proportional to the total export container flow of the ports in the aggregated shipping network.

Off-hire quotas: All data regarding the off-hire of leased containers are estimated for the year 2010 based on the interviews with the leasing companies (Abram, 2012, pp. 91).

- Monthly allowed off-hire quota for all leased containers available at carrier's disposal at the beginning of a month – 0.15;
- Additional port-related quotas for the off-hire of leased container are specified in Table 6.8.

Table 6.8: Port-related off-hire quotas in 2010

Unaggregated ports	Off-hire quota	Aggregated ports	Off-hire quota
NAM	0.14	EU	0.14
NY SAV	0.05 0.05	ECNA	0.10
LA VAN	0.05 0.05	WCNA	0.10
SIN	0.17	SIN	0.17
SHG	0.17	SHG	0.17
HK	0.17	HK	0.17
TOK	0.15	TOK	0.15

Source: Abram (2012), p. 91

It must be noted that the off-hire quotas are distributed between ports in a way that their sum for the whole network is equal to 1. The off-hire quotas in the aggregated ports are summarized respectively.

6.2 Scenarios

The main factor that affects container management decisions is the total transportation cost, which includes unit shipping cost on a sea leg and terminal handling charges on both ends of the maritime shipment. The shipping cost on a vessel consists of daily fixed cost per TEU and a variable cost per TEU-mile.

A number of studies assume no cost for empty containers since empty boxes can be shipped using available capacity on carrier's own vessels. However, in order to ensure a more realistic decision-making, at least fuel and handling charges must be still applied. Moreover, in a season of extreme container shortage in Asia, ocean carriers may charter additional vessels only for repositioning of empty equipment from regional hubs to the ports. As a result, two main scenarios of empty container repositioning are introduced for the case study:

A. Full shipping cost per empty TEU on a vessel,
B. Only fuel component in shipping cost per empty TEU.

The given scenarios are then tested in different settings, which consider:

- Transport demand pattern: flat and with seasonal fluctuations;
- Financial aspects: cost of capital tied up in leased inventories, additional repair cost for leased containers;
- Managerial aspects: not pre-defined or minimally required lease duration, restriction of leasing volume, slot purchasing from other carriers;
- Technical/other aspects: inadequate total vessel capacity for empty repositioning, different Traffic/Fleet ratio.

Transport demand pattern: Two cases of container traffic fluctuation are introduced. The "Off-Peak Season" case implies the decline in the shipping volumes in the middle of the planning period (e.g. after the New Year, before spring), while "Peak Season" assumes a strong increase in the transport demand during the planning time (e.g. before Christmas time). The peak-to-peak amplitude is set to 5% and 10% of an average annual shipping volume (Figure 6.4 and Figure 6.5).

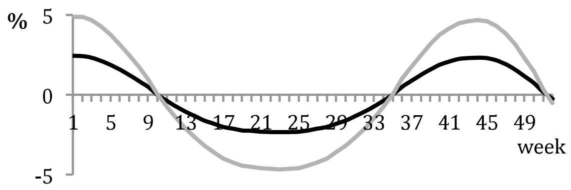


Figure 6.4: Off-peak season in container traffic

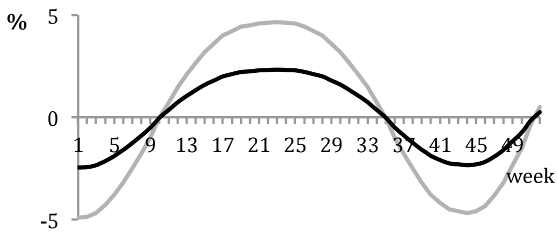


Figure 6.5: Peak season in container traffic

Financial aspects: Since finances invested in leased inventory cannot be used in other business operations, this cost of capital represents the lost return. This cost is, however, not an out-of-pocket expense, but rather an opportunity cost. In order to analyze the impact of the opportunity cost on leasing decisions, scenarios with and without consideration of the cost of capital tied up in leased inventories are introduced.

The risk of damage and the possible necessity of repair for leased containers can also affect the decisions on leasing. Repair cost in most of the scenarios is set to $100 per TEU.

Managerial aspects: The incorporation of minimum lease duration into the model reflects a more realistic condition for the short-term leasing option. Thus, most of the scenarios include the requirement of weighted-averaged lease duration of 3 months (13 weeks) minimally. At the same time, in order to analyze the leasing decisions in a more favorable setting, the scenario with unconditional lease duration is also introduced.

Furthermore, the leasing companies can limit the quantity of containers presented for the short-term leasing. Restriction of leasing introduced in scenarios of the case study assumes the limitation of leased number in total carrier's container inventory to 1%.

Finally, the scenario with slot purchasing option allows acquiring an additional capacity for repositioning of empty containers on the vessels of other carriers. The price of a slot is set to 110% of the shipping cost on the carrier's own vessels, and the purchasing capacity is unlimited.

Technical aspects: The scenario with inadequate vessel capacity assumes 20% fewer slots for empty containers on the backhauls to Asia.

A different Traffic/Fleet ratio models various levels of total container inventory. If the ratio is greater, then the total number of containers available for the shipping orders is smaller.

6.3 Result interpretation

6.3.1 Computational time

The model with all scenarios is created in AMPL (A Mathematical Programming Language) format and solved using Gurobi 6.5.0 (Gurobi Optimization, 2015), running under 2.5 GHz Intel Core i5 processor with 16 GB RAM. The computational efficiency of the solver applied to the model as an integer (IP) and linear (LP) program is shown in Table 6.9. The model is tested with its basic formulation without the introduction of the container travel time in the inland region, and with the extended formulation that considers inland container movements. It must also be noted that certain Gurobi parameters were tuned. The feasibility tolerance for integer variables is changed to 1×10^{-2}, the optimality tolerance for reduced cost is set to 1×10^{-3}, and the relative MIP optimality gap is fixed to 1×10^{-2}.

Computational results show that even with relaxed parameters for integer variables Gurobi solver enables a good performance of the basic model in a reasonable time for the smaller instances. However, for a larger planning horizon, the user waiting time increases significantly. The introduction of container travel time in the inland region also increases the computational time due to a larger number of variables in the extended model. The user waiting time depends to a large extent on leasing decisions. The solving process becomes more time expensive with a larger portion of leased containers in the total inventory.

Table 6.9: Computational time (CPU) for test instances with different planning horizons solved by Gurobi

Horizon (months)	Time periods (weeks)	Number of variables	Number of constraints	CPU time (sec) for IP	CPU time (sec) for LP	Optimality gap (%)
Basis model without container turn-around in inland region						
3	26	537508	317787	570	10	5×10^{-3}
6	39	1150920	675176	1293	27	4×10^{-4}
12	52	1994160	1165050	MEM	73	–
Extended model with container turn-around in inland region						
3	26	539272	319565	731	12	9×10^{-3}
6	39	1153410	677682	2068	35	6×10^{-4}
12	52	1997380	1168280	MEM	83	–

MEM - memory is not sufficient for the process to complete.

In order to study the leasing decisions on the longer planning period, the model was solved with the relaxed integrality constraint, and the results are discussed in the following chapters.

6.3.2 Validation process

Validation is an important step in the model development that reveals if a model that describes a certain system or a certain behavior does so adequately for the model's intended use (Miser, 1993). In other words, validation is concerned with representational accuracy.

A fundamental issue that underlies the validation process is, however, its subjectivity. In many ways, the validation is subjective due to the personal choice of tests, a criterion for measuring the validity of the tests or the model, etc. (McCarl and Apland, 1986). Moreover, in the process of modeling the reality, a number of simplifications are usually made: e.g. assumptions of approximate linearity, etc. Such simplifications can alter the perception of the real system but will model it accurately. As a result, Finlay (1988) suggests expressing the validation process as "testing model's appropriateness against the perceived reality of the real world system". In this case, the validation is rather concerned with demonstrating that the relationships that make up the model and the model behavior are appropriate.

Approaches to validation vary widely depending on a problem class, a type of the model, a modeling method used, etc. Ideally, adoption of the model by decision-makers is needed to provide the ultimate validation test. In other cases, a model, program or a policy must be in operation over a certain time in order to establish its strengths and weaknesses (McCarl and Apland, 1986) These methods are, however, very expensive. As a result, the models are often validated through the comparison of their results with historical outcomes or events in the real-world system. It must be, however, noted that there might be not enough historical data for such comparison, especially in the cases when a strategy or a policy is being evaluated. In this situation, it can be acceptable to validate the model by conducting different case studies. These case studies allow to test the strategy and to gain further insight into the causes and effects within a given framework (Muilerman, 2001, pp. 104-109; Platz, 2009, pp. 25-26).

Finally, Finlay and Wilson (1987, 1990) also claim that it is not enough just to compare the model's results with the outcomes of the real system or the experts' statements. Due to the loss of knowledge about the assumptions of the model and its simplifications, the absolute reliance on the experts' opinion is not sufficient (Finlay and Wilson, 1990). Rather than just simply validate the model's result, it is proposed to ask further questions: e.g. the questions about the range of model's application, the sensitivity of model's decisions and model's results to the parameter changes, etc.

In our case, the validation by results represents difficulties. Data on container traffic and container deployment in an ocean carrier's service network is associated with a high level of confidentiality. Only limited or parts of the data regarding empty container repositioning are available for the model's validation. As a result, the inability to present the extensive carrier's data with the purpose of its comparison with the results of the model limits the validation process in the given study.

However, another possibility for demonstrating the realistic behavior of the model lies in conducting the sensitivity analysis. It is often used in validation of dynamic simulation models. At the same time, Finlay and Wilson (1988) claim that sensitivity analysis represents an acceptable method for validation of all decision support systems since it can show the realistic relations in the model.

The following sections describe the results of the model in different settings to demonstrate the model's "appropriateness" while taking into account the assumptions and simplifications made in the modeling process. Certain references to the real-world data or practices are also provided throughout the description of the model's results, although the data is fairly limited.

6.3.3 General results of container management with the short-term leasing option in different scenarios

Global empty container repositioning: Results of container management model show that the volume of empty container repositioning in scenarios with an adequate vessel capacity makes up around 18% in total transportation. This value resembles the data of Drewry Shipping Consultants, which estimated a share of global empty container movements close to 20% of all maritime container transportation (Drewry Shipping Consultants, 2010). At the same time, the introduction of leasing reduces a share of global repositioning (Table 6.10).

A portion of short-term leased containers in total container inventory: Results of the model in different scenarios show that the short-term leasing option is economically justified only in specific cases: e.g. when the vessel capacity is limited for all needed empty container repositioning, and the container shortage is strong (Table 6.10). Even when the shipping cost of empty containers is very high, the short-term leasing still does not represent a reasonable option. It is more profitable to reject certain shipping demands in the ports with big container shortage rather than lease additional equipment. However, if the repositioning cost is very high, and an ocean carrier can negotiate more favorable leasing conditions (specifically, reduced drop-off charges), only then the short-term leasing decisions can be considered in container management. It must also be noted that the shipping companies rarely pay a full price for the repositioning of their empty equipment since containers are being typically piggybacked using the available capacity on their own vessels. As a result, the short-term leasing is being normally avoided in reality, and used only in certain cases, as it is also shown in the proposed model.

Presented result regarding leasing resembles the shipping practices. Based on the interview with an ocean carrier, the short-term leasing option is being avoided due to the high off-hire charges, namely: drop-off and repair fees. At the same time, there can be cases, when a shipping company can negotiate almost zero drop-off charges. Repair fees are also being negotiable. For example, an ocean carrier can pay a guaranteed flat repair fee for all leased containers, while the leasing company covers the actual damages. As a result, the short-term leasing option is still used in certain cases, however, in fairly small quantity. It must also be noted that scenarios in the given case study describe rather extreme shipping conditions: i.e. equal shipping price for loaded and leased containers, tight limitation of vessel capacity. As a result, the resulted volumes of short-term leasing in given scenarios appear to be somewhat higher than in reality. At the same time, the relations between parameters as well as utilization patterns still resemble the real-world situation.

The model's results show that one of the factors that affect the leasing strategy is the lease duration. The requirement of minimum lease time has a significant effect on the utilization pattern of leased equipment, while the volume of leasing is not changed much.

When the minimum lease duration is required, containers are forced to be reused for multiple trips in the shipping network. As a result, they keep circling on the transpacific route between North American West Coast (WCNA) and Asia (Table 6.12). Such round trips represent the cheapest shipping option. However, when the minimum lease duration is not required, containers can be used only for specific trips. In this case, they are being assigned primarily to the round trips on the Europe–Asia route with the backhauls to the ports, associated with a very expensive cost of empty container repositioning or/and a very high repositioning flow. Even though such round trips are more costly, containers are making fewer trips. Moreover, the assignment of leased containers on the Europe–Asia connection frees vessel capacity for the cheapest repositioning options of own container surpluses on the transpacific route. In both cases, the number of lease for one-way trips is very limited. Such model's result resembles the shipping practices. According to the interviews with the leasing companies, the leasing capacity for one-way trips is kept very limited. Furthermore, if the ocean carrier has a lot of trip lease, the lessor tries to prohibit it through different measures.

Table 6.10: Selected resulting parameters in different scenarios

Scenarios	Resulting parameters					
	Profit ($Mil.)	ECR (%)	STL (%)	u (%)	UR_o (%)	UR_l (%)
A1. Full shipping cost per empty TEU						
No leasing, no demand rejection	3003.1	18.29	–	–	40	–
No leasing, with demand rejection	3003.2	18.14	–	0.29	40	–
Leasing: LeaseT=3	3003.2	18.14	–	0.29	40	–
Leasing: 0.8Doff, LeaseT=3	3004.0	18.05	3.18	0.07	39	53
Leasing: 0.8Doff, LeaseT=0	3004.1	18.05	3.34	0.07	39	77
A2. Full shipping cost per empty TEU. Reduced vessel capacity						
No leasing, with demand rejection	2980.2	16.53	–	3.22	38	–
Leasing: LeaseT=3	2980.2	16.53	–	3.22	38	–
Leasing: 0.9Doff, LeaseT=3	2980.4	16.56	0.80	3.07	38	59
Leasing: 0.9Doff, LeaseT=0	2980.5	16.56	0.97	3.06	38	88
Leasing: 0.8Doff, LeaseT=3	2981.5	16.52	4.06	2.72	37	61
Leasing: 0.8Doff, LeaseT=0	2981.9	16.50	4.95	2.70	37	83
Leasing: 0.8Doff, LeaseT=0, Slot purchase	2996.8	18.29*	–	–	40	–
B1. Only fuel component in shipping cost per empty TEU						
No leasing, with demand rejection	3448.6	18.29	–	–	40	–
Leasing: LeaseT=3	3448.6	18.29	–	–	40	–
Leasing: LeaseT=3, Doff=0	3448.6	18.29	–	–	40	–
B2. Only fuel component in shipping cost per empty TEU. Reduced vessel capacity						
No leasing, with demand rejection	3370.2	16.77	–	2.79	38	–
Leasing: LeaseT=3	3370.2	16.77	0.12	2.78	38	78
Leasing: 0.9Doff, LeaseT=3	3371.0	16.73	2.66	2.53	38	85
Leasing: 0.9Doff, LeaseT=0	3371.3	16.72	3.49	2.46	37	90
Leasing: 0.9Doff, LeaseT=0, Slot purchase	3390.4	18.04**	–	0.47	40	–
Seasonal fluctuations in scenarios with full shipping cost per empty TEU Leasing: 0.8 Doff, LeaseT=3; No demand rejection						
Off-peak 10%	3003	18.08	3.74	–	38.8	52.9
Off-peak 5%	3004	18.08	3.50	–	38.9	52.8
Flat	3004	18.08	3.50	–	38.9	52.5
Peak 5%	3005	18.09	2.98	–	39.0	52.3
Peak 10%	3005	18.10	2.74	–	39.1	52.2
Seasonal fluctuations in scenarios with full shipping cost per empty TEU Leasing: 0.8 Doff, LeaseT=0; No demand rejection						
Off-peak 10%	3003	18.02	4.59	–	38.3	74.8
Off-peak 5%	3004	18.04	4.26	–	38.4	75.2
Flat	3004	18.06	3.74	–	38.5	75.3
Peak 5%	3005	18.07	3.47	–	38.6	75.3
Peak 10%	3005	18.08	3.09	–	38.7	75.8

* Incl. 3.3% - repositioning on purchased slots in the total transportation;
** Incl. 1.2% - repositioning on purchased slots in the total transportation.

Profit – total profit from container management; **ECR** – share of empty container repositioning in the total transportation; **STL** – share of leased number in the total inventory; **u** – share of unsatisfied demand in the total traffic; **UR_o**, **UR_l** – utilization rate of own and leased containers, respectively.

LeaseT – minimum lease duration; **0.9Doff** and **0.8Doff** – reduced drop-off charges by 10% and 20%, respectively.

Finally, the model's results also show that the pattern of container traffic affects the volume of leasing and empty container repositioning. The Scenario with a Peak season is characterized by the large increase in shipping demand in the middle of the planning horizon. In this case, a greater volume of empty containers can be relocated in advance to certain Asian ports to prevent the future shortage. The Off-Peak scenario is, on the contrary, characterized by increased demand right in the beginning. As a result, there is less opportunity to ship empty containers in advance. As a result, more containers are being leased additionally in the beginning, and used with a purpose of avoiding certain most expensive repositioning cases.

Deployment of leased containers in the shipping network: The case study assumes that Singapore has the highest export flow and the strongest container shortage (see Appendix A Table A.5). It is also one of the most expensive destinations for container repositioning from North America. As a result, the Singapore port generates the greatest empty container inflow and the highest total repositioning cost, consequently.

Taking into account the given settings, scenarios with a very high shipping cost of empty TEU have the predominant on-hire of leased equipment in Singapore. However, when the vessel capacity is limited, the cheapest options for the repositioning are much more restricted. A more costly relocation scenario needs to take place. Since Hong Kong is associated with the most expensive shipping cost from all ports in the shipping network, the on-hire of additional equipment shifts from Singapore to Hong Kong (Table 6.11). Taking into account the given setting, the described influence of the repositioning cost on the on-hire decisions appears to be logical.

Table 6.11: Distribution of the short-term leasing between Asian ports in selected scenarios

Scenarios	**Distribution of leasing between ports in Asia**			
	SIN	SGH	HK	TOK
A1. Full shipping cost per empty TEU				
0.8Doff, LeaseT=3	100	–	–	–
0.8Doff, LeaseT=0	100	–	–	–
A2. Full shipping cost per empty TEU. Reduced vessel capacity				
0.8Doff, LeaseT=3	64	–	36	–
0.8 Doff, LeaseT=0	62	–	38	–
B2. Only fuel component in shipping cost per empty TEU. Reduced vessel capacity				
LeaseT=3	3	–	97	–
0.9Doff, LeaseT=3	1	–	99	–
0.9Doff, LeaseT=0	1	–	99	–

LeaseT – minimum lease duration; **0.9Doff** and **0.8Doff** – reduced drop-off charges by 10% and 20%, respectively.

Table 6.12: Distribution of leased container traffic in the transport network in selected scenarios

Scenarios	Route	Total traffic on a route (%)	Round trips in the total traffic (%)	• Loaded headhaul from Asia	• Loaded backhaul to Asia	• Empty backhaul to Asia	One-way trips in the total traffic (%)	Leased container utilization (%)	Leased number in the total inventory (%)	One-way lease in the total leasing (%)
A1. Full shipping cost per empty TEU										
0.8Doff, LeaseT=3	AS-EU	**8**	4	2	2	0	4	53	3.2	0.3
	AS-NA	**90**	84	43	2	41	6			
	EU-NA	**1**	1	0	0	0	0			
0.8Doff, LeaseT=0	AS-EU	**44**	39	19	18	1	6	77	3.3	0.3
	AS-NA	**53**	47	24	1	23	6			
	EU-NA	**2**	1	1	1	0	1			
A2. Full shipping cost per empty TEU. Reduced vessel capacity										
0.8Doff, LeaseT=3	AS-EU	**15**	9	5	5	0	5	61	4.1	0.4
	AS-NA	**84**	80	40	7	33	5			
	EU-NA	**1**	0	0	0	0	1			
0.8Doff, LeaseT=0	AS-EU	**53**	47	23	20	3	6	83	5.0	0.5
	AS-NA	**46**	40	19	4	15	6			
	EU-NA	**1**	0	0	0	0	1			
B2. Only fuel component in shipping cost per empty TEU. Reduced vessel capacity										
LeaseT=3	AS-EU	**5**	1	1	1	0	4	78	0.1	0.01
	AS-NA	**94**	89	45	34	11	5			
	EU-NA	**1**	0	0	0	0	1			
0.9Doff, LeaseT=3	AS-EU	**7**	3	1	1	0	4	85	2.7	0.2
	AS-NA	**92**	88	44	39	5	4			
	EU-NA	**1**	0	0	0	0	1			
0.9Doff, LeaseT=0	AS-EU	**69**	62	31	26	5	7	90	3.5	0.4
	AS-NA	**29**	23	11	9	2	6			
	EU-NA	**2**	0	0	0	0	1			

LeaseT – minimum lease duration; **0.9Doff** and **0.8Doff** – reduced drop-off charges by 10% and 20%, respectively.
AS – Asia; NA – North America; EU – North Europe.

Note: The sums might not be equal its 100% value due to the rounding error.

Two main patterns of container utilization can be distinguished depending on the leasing conditions. When the minimum lease duration is required, containers are being on-hired in Asian ports at the beginning of the planning period, and gradually used for the trips (Figure 6.7a,c). The storage of leased inventories before assignment allows meeting the requirement of minimum lease time more easily, since lease duration is calculated in the model as an average, weighted by the container volume in a specific usage (storage, shipping, repositioning, etc.). The requirement of minimum lease duration also forces containers to keep circling on the transpacific route between WCNA and SHG, which presents the cheapest round trip option in the shipping network (Figure 6.8a,c). A small portion of the lease is used for one-way trips to all regions. This leasing option is the most efficient, since it provides additional containers in the ports of their shortage, avoiding, at the same time, the repositioning of empty leased equipment back to Asia. However, a large volume of the one-way trip lease is prohibited by the limited off-hire quotas in European and North American ports. As a result, leased equipment must be returned to Asia for the further reuse or the off-hire there. An empty backhaul to Asia is assigned to the cheaper repositioning option, while a loaded backhaul is assigned to the customer demands with the most expensive shipping destination. In the later case, the relocation of own empty equipment on the most expensive shipping connections can be reduced or avoided, resulting in a more economical repositioning plan.

When the minimum lease duration is not required, there is no need for the long circling of leased equipment in the shipping network. In this situation, containers are on-hired in Asia, and more immediately used for the trips (Figure 6.7b,d). Moreover, leased containers tend to be assigned more to the Europe-Asia route, for round trips with the loaded backhauls to the ports associated with the highest repositioning cost (Figure 6.8b,d). Though such trips are more expensive, more empty containers can be repositioned to Asia from WCNA at a much cheaper cost. One-way trips to Europe are also much less expensive in view of drop-off charges.

In all scenarios, a portion of one-way trips in total traffic of leased containers is very small, less than 1% of total leasing (Table 6.12). The smaller the leasing volume, the lower the share of one-way trips. This relation appears to be logical since the off-hire quota is calculated depending on the lease volume. Leased containers are also dropped off in all regions after their usage for different trips. At the same time, the main portion tends to be off-hired in European and North American ports (Figure 6.9).

The presented results resemble the leasing practice of ocean carriers. The shipping companies on-hire containers primarily in Asia and use them on all shipping routes with the off-hire in all regions. At the same time, it is important for the carriers to negotiate the highest drop-off quotas in Europe and North America. The particular utilization patterns for leased containers can vary greatly from company to company, depending on the negotiated leasing conditions, previous leasing history, and leasing volumes. In all cases, lessors discourage a large number of one-way trip leases. According to the interviews with the ocean carriers, containers are on-hired and immediately used for the shipments. A special case, however, can present the situation with the newly built containers. The lessor can drop them off at carrier's depots, where they can be stored, and gradually used for the shipments.

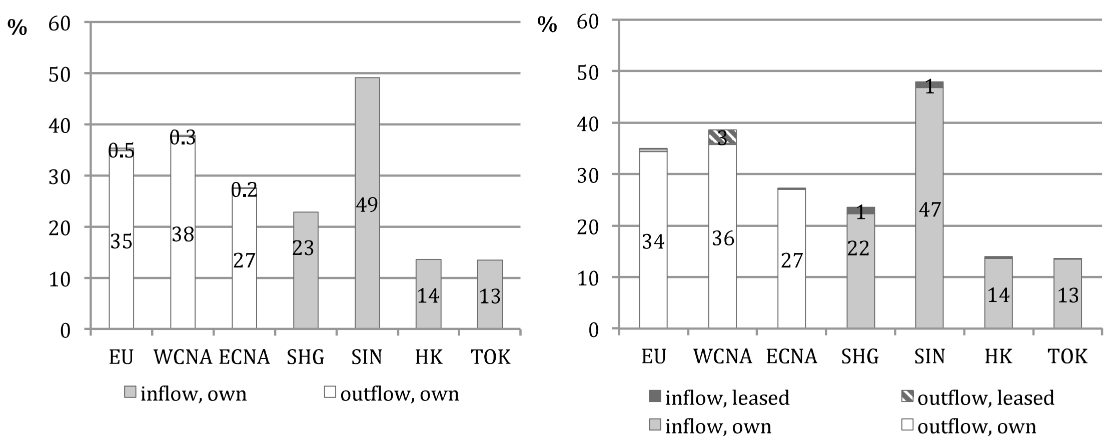
Demand rejection: Finally, it must be noted that when empty container repositioning represents a very high cost, and the leasing conditions are not particularly favorable for the carrier, it is more profitable to reject certain customer orders than to use the short-term leasing option (Table 6.10). The rejection of certain shipping demands is also economically justified in the situation with limited vessel capacity. As a result, the tactical planning of empty container repositioning that allows deciding, which customer orders are not profitable to satisfy in the situation of given vessel and inventory capacity, enables a higher profit from total container management.

A more detailed analysis of the model's results in selected scenarios is presented in the following sections.

6.3.4 Scenario A: Full shipping cost per empty container

The main assumption of scenario A is an equal shipping cost for full and empty containers. Additional aspects involve the limited storage capacity, the lease duration requirement of 3 months, full drop-off charges, a flat repair fee, and consideration of the cost of capital tied up in leased inventory.

Since the storage capacity is limited, empty container repositioning is forced from all ports, even the most expensive ones, located on the East Coast of North America (ECNA) (Figure 6.6a). Main empty container flow is focused on the transpacific route from the West Cost of North America to Eastern Asia (WCNA-SHG/TOK), and on the connection from Europe to Southeastern Asia (EU-SIN). This repositioning represents the cheapest total shipping cost. To balance the inventory stock in the situation of very tight restrictions on storage capacity, a very small portion of own containers is also being exchanged between West and East Coast of North America (WCNA-ECNA), as well as between East Coast of North America and Europe (ECNA-EU). Such repositioning, however, does not exceed 0.5% of the total empty container flow in the network.



a) Scenario without leasing option b) Scenario with leasing option

Figure 6.6: Inflow and outflow of leased and owned empty containers in the ports

In the case when the ocean carrier can negotiate more favorable leasing conditions (particularly, the reduced drop-off charges), the short-term leasing option gives the possibility to reduce or avoid certain most expensive empty container repositioning cases. In this situation, containers are being leased and used in the ports associated with the most expensive repositioning inflow, while own containers can be relocated on connections with a cheaper shipping cost. The comparison of empty container repositioning with and without leasing option (Figure 6.6a,b) shows the change in empty container in-/outflow in ports with the introduction of the short-term leasing option.

Leased containers are being on-hired in a port with the strongest container shortage and the highest repositioning cost: e.g. Singapore.

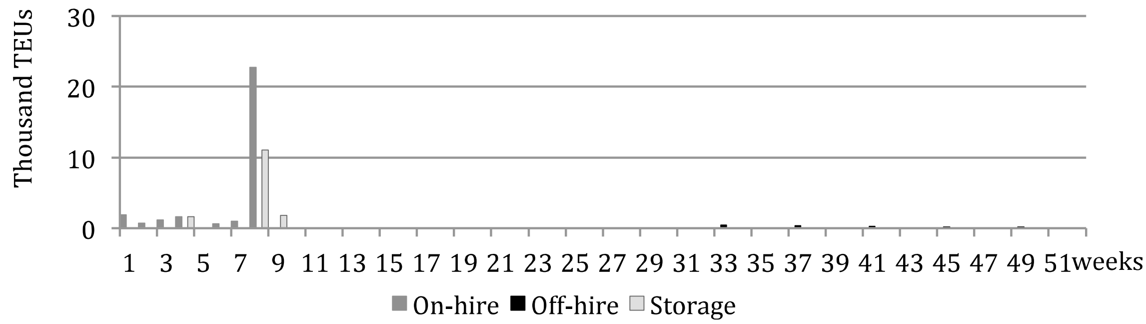
Since certain minimum duration is required, a significant portion of leased equipment is forced to circle on the transpacific route, which presents the cheapest round trip options (Figure 6.8a,c). A large portion of leased equipment is assigned from SIN to WCNA and back to SHG for the subsequent reuse or gradual off-hire there. The other smaller portion of leased containers in WCNA is returned to SIN. Even though such empty backhauls of leased equipment is costly, fewer own containers can be repositioned to SIN from ECNA at even higher cost. Instead, own container inventories can be sent from ECNA to other cheaper repositioning destinations: e.g. to TOK.

The rest of leased container flow takes a form of one-way trips to all regions with the subsequent off-hire there. Such usage of leasing avoids the most expensive repositioning cases of own equipment e.g. WCNA-SIN, ECNA-HK/SIN, or EU-TOK/HK. There is also a small portion of round trips on Europe–Asia route with the loaded backhauls to the ports, associated with the maximal shipping cost. In this case, repositioning of own equipment can shift to the cheaper connections: e.g. from EU-TOK to EU-SIN.

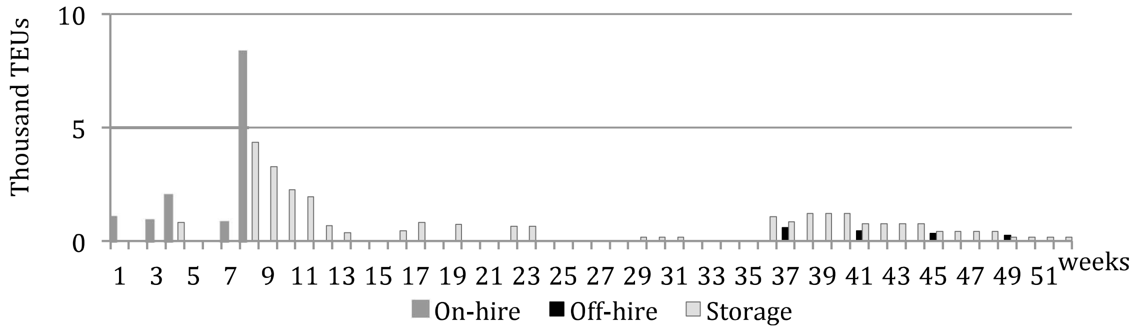
As a result, the usage of leased containers for round trips with the loaded backhauls to the most expensive repositioning destinations, as well as a portion of one-way trip lease enable to achieve a more profitable repositioning plan for own inventories. For example, the flow of empty containers on the expensive shipping connections WCNA/ECNA-SIN or EU-TOK/HK can be reduced, while the flow on the cheaper connections WCNA/ECNA-TOK or EU-SIN can be increased.

Effect of limited vessel capacity: When vessel capacity is limited, the possibility of a cheaper plan for empty container repositioning is more limited. As a result, a portion of leased containers is on-hired additionally in Hong-Kong – the most expensive repositioning destination for empty containers. Due to the limited vessel capacity for empty boxes, more leased containers are returned back to Asia loaded with cargo (Figure 6.8c). Moreover, more leased containers are assigned from the Asian ports to Europe with loaded backhauls to the most expensive shipping destinations. In this case, the repositioning of own empty equipment can shift from the most costly connections to the cheaper ones: e.g. from EU-HK/TOK to EU-SIN.

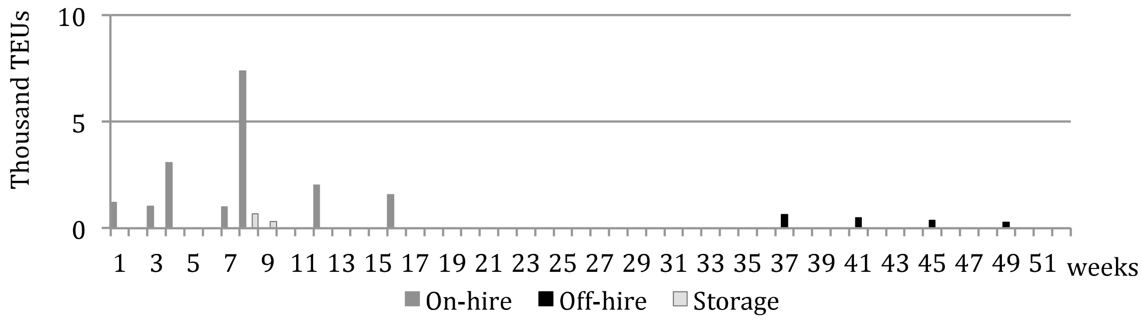
a) Singapore.
Leasing with the minimum lease duration



b) Singapore.
Leasing with no minimum lease duration

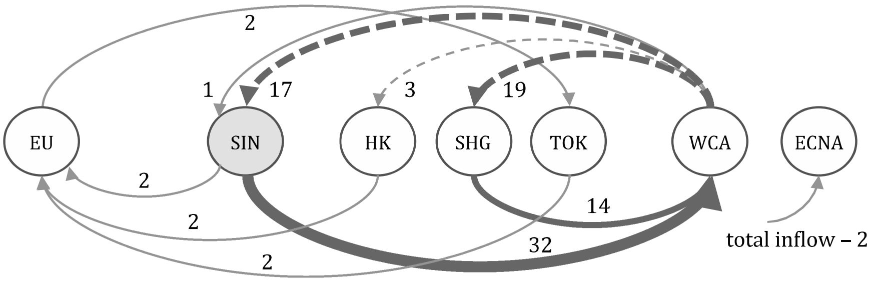


c) Hong Kong.
Leasing with the minimum lease duration. Vessel capacity is limited

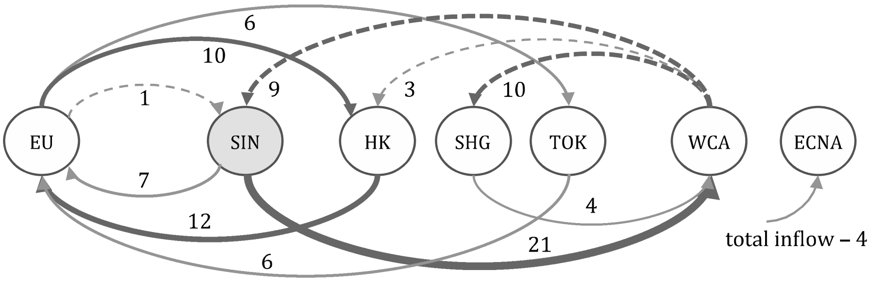


d) Hong Kong.
Leasing with no minimum lease duration. Vessel capacity is limited

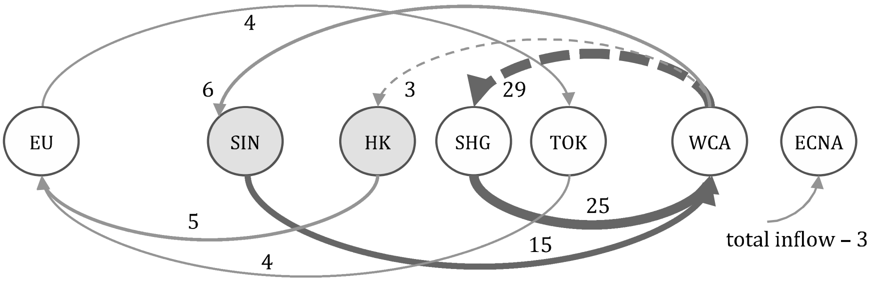
Figure 6.7: Leasing, storage, and off-hire of containers in an Asian port over the planning period (scenario A with reduced drop-off fees by 20%)



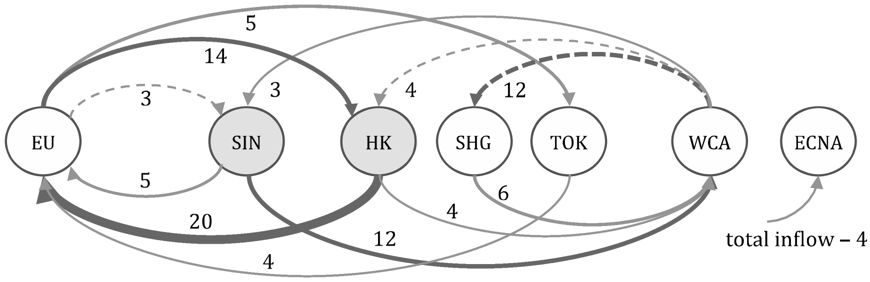
a) Leasing with the minimum lease duration



b) Leasing with no minimum lease duration



c) Leasing with the minimum lease duration. Vessel capacity is limited



d) Leasing with no minimum lease duration. Vessel capacity is limited

Figure 6.8: Distribution of leased container traffic in the transport network[4] (scenario A with reduced drop-off charges by 20%)

[4] A very small container flow under 1% in the total shipping with leased containers is omitted in the presentation. Therefore, the sum of numbers might not be equal 100%.

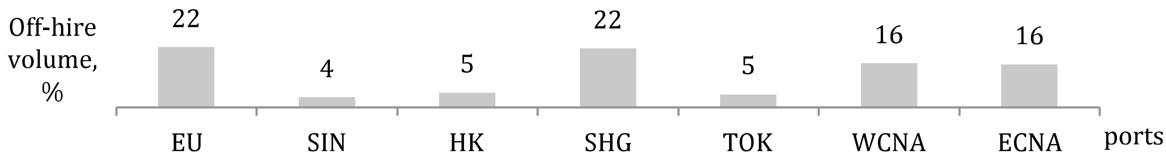


Figure 6.9: Typical distribution of the off-hire volume in the ports (scenario A with reduced drop-off fees by 20%)

Effect of the minimum lease duration: If no minimum lease duration is required, containers do not need to circle a long time in the shipping network. Containers are on-hired for specific trips and immediately used (Figure 6.7b,d). Since the lessors prohibit large volumes of the one-way trip lease, on-hired containers are assigned primarily for round trips with the empty backhauls on possibly cheaper connections, or with loaded backhauls to the most expensive repositioning destinations (Figure 6.8b,d). At the same time, there is much less need for recurring reassignment of leased equipment to further shipments. As a result, the usage of leased containers shifts more to the Europe-Asia route. This shift enables to free some vessel capacity for the cheapest options of empty container repositioning on the transpacific route: e.g. on connections WCNA-SHG/TOK. A cheaper repositioning plan of own container inventories can be achieved.

Demand rejection in the situation of reduced vessel capacity: Finally, due to the tighter vessel capacity for empty container repositioning, around 3% of total annual shipping demand is being rejected on connections with the possibly lowest profit (Table 6.13). However, in certain cases, due to the shortage of own equipment, it becomes reasonable to satisfy less profitable customer orders with leased containers using the cheapest leasing options (e.g. one-way trips SIN-EU), and reject more profitable customers that are associated with much higher leasing cost (e.g. one-way trips SIN-ECNA).

Table 6.13: Distribution of unsatisfied demand in % (on the left), and the profit from the shipment in $/TEU (on the right) in scenario A with limited vessel capacity[5]

Destination / Origin	EU	ECNA	WCNA
TOK	– / 867	– / 1603	– / 1169
SIN	– / 1211	23 / 1619	52 / 1086
HK	23 / 978	– / 1672	2 / 1147

Sensitivity analysis for scenario A

In order to study the impact of different factors on the leasing decisions, the sensitivity analysis is performed. However, since leasing decisions are not profitable in a normal situation, the scenario with limited vessel capacity and the reduced drop-off charges (20%-reduction) is taken for the study. The leasing conditions also include the requirement of minimum lease duration (3 months). The values of influencing parameters are changed by

[5] Leasing conditions include reduced drop-off charges by 20% and no requirement of minimum lease duration

10%, and the results are analyzed taking into account the effect on the total profit from container management (Figure 6.10) and the leased number (Figure 6.11).

Analysis of leasing decisions and the total profit from container management: Results of the sensitivity analysis show that the financial parameters related to shipping and storage of empty containers carry the greatest potential for optimization since they represent an essential part of the total management cost. These parameters also influence leasing decisions, however, not as primary factors, because the short-term leasing is expensive in any case (Figure 6.11). In the given scenario, the shipping cost has the strongest influence in the mentioned group, as it comprises both variable and fixed costs of a slot, and thus, makes up the highest portion in the total repositioning expenses. The lower the shipping cost of the empty own container, the less profitable leasing decisions in container management (Figure 6.11). At the same time, the storage cost has an opposite effect. A lower storage cost creates better conditions for leasing since leased equipment is often being stored before usage or the off-hire in the given setting.

It must also be noted that in the situation of limited vessel capacity and high empty container repositioning cost, there is a portion of customer orders that is being declined for shipping. A portion of rejection in total transport volume is different depending on a change of various parameters. For example, an increase in the shipping cost without respective increase in the freight rates makes it reasonable to reject much more customer orders compared to the basic scenario. As a result, the necessity of short-term leasing reduces. Therefore, the line that represents the change of leased number with a change of shipping cost has a piecewise linear character (Figure 6.11).

The next factor that carries the next greatest optimization potential is the off-hire quota. It also has the strongest influence on container management and leasing decisions among other factors (incl. financial ones related to shipping and storage). The short-term leasing is typically very expensive due to the high drop-off and repair fees. However, it is still applicable in the given scenarios because of the limited vessel capacity for empty container repositioning. In this situation, the condition of how fast the leased equipment can be returned to the lessor, and specifically, how many containers can be returned in container surplus areas, affects the profitability of leasing decisions greatly. The increased off-hire quota makes the leasing conditions significantly better.

The higher off-hire quota enables more of leased containers to be returned in Europe and North America. In this way, the carrier can avoid additional repositioning of leased equipment back to Asia, and additional storage before the off-hire. This leads to a lower transportation and storage cost, resulting in a better value of the profit function. The interview with the shipping experts confirms such results. The off-hire quota is one of the most important parameters in the leasing conditions.

It must also be pointed out again, that the change of leased number and the total profit function with a change of off-hire quota has a piecewise linear line because of the additional influence of demand rejection. For example, the 10%-increase in off-hire quota not only creates incentives for greater leased number, which enables to avoid a high cost of certain empty container repositioning, but it also allows more customer orders to be accepted for shipping. As a result, the profit function has a much higher increase.

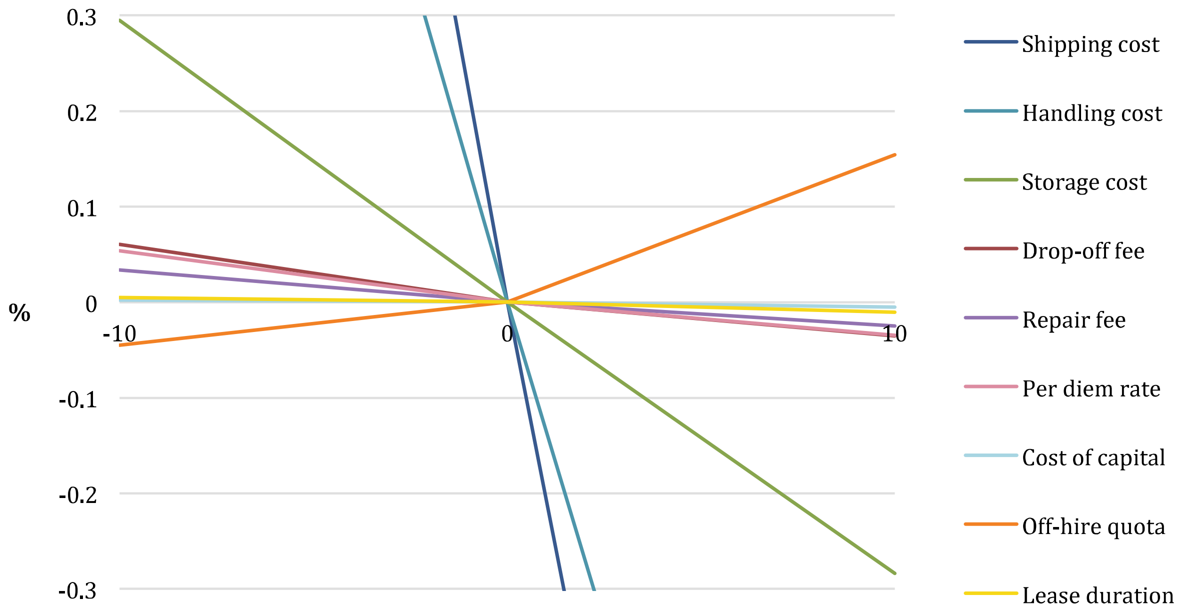


Figure 6.10: Change in the total profit from container management with a change of influencing parameters by 10% (scenario A with limited vessel capacity and reduced drop-off fees by 20%)

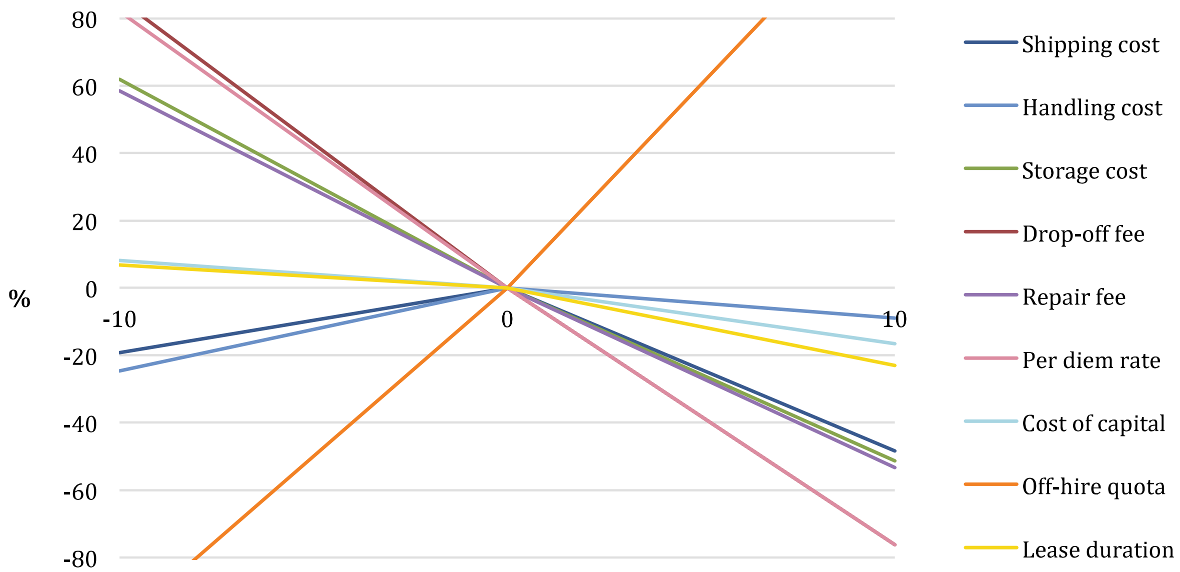


Figure 6.11: Change in the total leased number with a change of influencing parameters by 10% (scenario A with limited vessel capacity and reduced drop-off fees by 20%)

The next group of factors that has a strong influence on container management and leasing decisions are the drop-off fees and per diem rate. Both parameters affect the leased number in the same way: the lower the cost, the better the leasing conditions, and the higher the volume of short-term leasing. The effect of parameters on the usage of leased equipment is, however, somewhat different. The reduced drop-off charges encourage the return of leased containers in the regions of their surplus. In this case, additional repositioning of leased boxes back to Asia can be avoided. At the same time, the reduced value of per diem rate in the situation of high drop-off charges encourages the relocation of leased boxes back to Asia for the off-hire there.

The repair fee has a fairly small value in the given scenario, as it is assumed that an ocean carrier can negotiate a minimum flat rate for the container repair with the lessors. As a result, it does not have as strong influence on the leasing decisions as other mentioned parameters.

It is also worth mentioning that the results and relations in the model will depend on the shipping conditions at each carrier. It often happens that the largest ocean carriers negotiate better leasing conditions with the lessors. As a result, the carrier might pay minimum drop-off fees. These charges will be then insignificant in the decision-making process related to the container management and leasing. In this case, the off-hire quota and per diem rate are the only factors that play the decisive role in negotiations with leasing companies.

The other parameters like lease duration and the cost of capital tied up in leased equipment have a rather weak influence on leasing decisions as well as the total profit from container management.

6.3.5 Scenario B: Only fuel component in shipping cost per empty container

The main assumption of scenario B is the reduced shipping cost of empty containers. Additional aspects involve: the limited storage capacity in the ports, the required 3-months lease duration, consideration of the cost of capital tied up in leased inventories.

Reduction of total repositioning cost to fuel and handling charges makes the short-term leasing option economically unreasonable even in the situation with very favorable leasing conditions: e.g. with zero drop-off charges. Empty container repositioning to Asia covers all container shortage there and reaches over 18% in the total container transportation. This value is close to the data of Shipping Consultants, which estimated empty container movements as 20% of all maritime container transportation (Drewry Shipping Consultants, 2010). In order to cover the high repositioning expenses, all shipments, even not profitable ones, are accepted for the shipping.

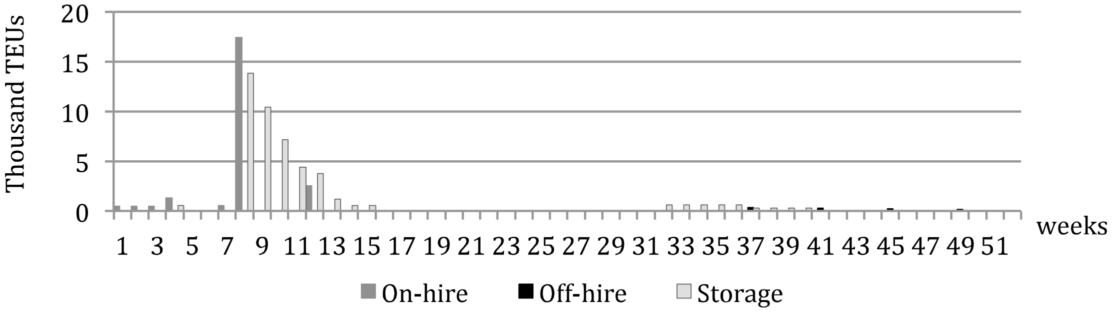
Short-term leasing in the situation of limited vessel capacity: The short-term leasing becomes reasonable only due to the inadequate vessel capacity for empty repositioning back to Asia. Depending on leasing conditions, its portion makes up from 3 to 5 percent in total container inventory (see Table 6.12). It must be noted, that a share of leasing in the given scenarios might be higher than in reality due to a fairly tight limitation of the vessel capacity for empty container repositioning back to Asia. At the same time, the results still show realistic relations in the model. For example, the results demonstrate that in more realistic shipping conditions (e.g. with reduced shipping cost per empty TEU) the short-term leasing option can be economically reasonable, but only in limited cases.

In the situation of limited vessel capacity, the possibility of empty container repositioning on all shipping connections, and especially, on the cheapest ones, is limited. As a result, fewer containers can be relocated in advance to the Asian ports to cover the future shortage of equipment. In this case, a portion of the additional equipment is on-hired in Hong Kong – the most expensive repositioning destination from all ports.

The same as in previous results, two main patterns of container utilization are being observed in the current scenario. When the minimum lease duration is required, containers are being on-hired at the beginning of the planning period, and slowly used for the shipments primarily on the transpacific route to WCNA with the loaded haulage back to Asia, and the further recurring reassignment there (Figure 6.12a and Figure 6.13a). Containers are being returned mainly to SHG, since it presents the cheapest repositioning option. Moreover, due to the tight vessel capacity for empty boxes, and the high-volume repositioning of own inventories, leased containers are returned back to Asia primarily loaded with cargo. The rest of leased equipment tends to be used for one-way trips to all regions with the subsequent off-hire there.

When there is no requirement of the minimum lease duration, equipment is on-hired in Hong-Kong and used more immediately for specific shipments without a need of its recurring reuse (Figure 6.12b). Since the long circling of leased containers is no longer forced, the main portion of the equipment is assigned to the trips on the Europe–Asia route with the back-haulages to the most expensive repositioning destination like EU-HK/TOK (Figure 6.13b).

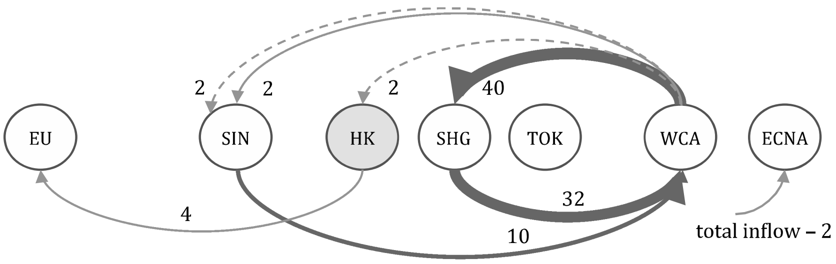
Finally, a small portion, around 2.5% of total annual transport demand, is also rejected as a result of limited vessel capacity for all needed container repositioning. Customer orders are rejected mainly for the shipping on the transpacific route from SIN, as it has the highest export volume, and, consequently, the greatest container shortage occurs there (Table 6.14). It is also reasonable to satisfy less profitable customer orders with leased containers using the cheapest leasing option (e.g. one-way trips HK-EU) but to reject more profitable customers that are associated with much higher leasing cost (e.g. one-way trips HK/SIN-ECNA). Another reason for rejecting the customer demand for the shipments to ECNA is avoiding the most expensive empty container repositioning from there.



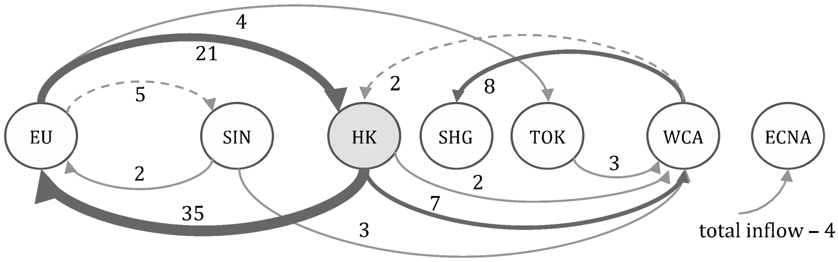
a) Leasing with the minimum lease duration

b) Leasing with no minimum lease duration

Figure 6.12: Leasing, storage, and off-hire of leased containers in HK over the planning period (scenario B with limited vessel capacity and reduced drop-off fees by 10%)



a) Leasing with the minimum lease duration



b) Leasing with no minimum lease duration

Figure 6.13: Distribution of leased container traffic in the transport network[6] (scenario B with limited vessel capacity and reduced drop-off fees by 10%)

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[6] A very small container flow under 1% in the total shipping with leased containers is omitted in the presentation. Therefore, the sum of numbers might not be equal 100%.

Even though such round trips are more expensive compared to the trips on the transpacific route, the shift of leased container flow to the Europe–Asia route frees the vessel capacity for cheaper repositioning options from WCNA to Asia.

Table 6.14: Distribution of unsatisfied demand in % (on the left), and the profit from the shipment in $/TEU (on the right) in scenario B with limited vessel capacity[7]

Origin \ Destination	EU	ECNA	WCNA
TOK	10 / 1390	– / 2090	– / 1370
SIN	0 / 1580	17 / 2300	57 / 1385
HK	3 / 1420	10 / 2103	2 / 1350

Effect of slot purchasing option in case of limited vessel capacity: The possibility of slot purchasing for empty container repositioning on the vessels of other carriers makes the leasing option no more economically justified. It is assumed that a carrier can negotiate a purchasing price of the slots only 10% higher than the full cost of the slots on its own vessels. Moreover, the purchasing capacity is not limited in the case study. In such conditions, a fairly high number of empty equipment – 11% of total container repositioning – is shipped on the vessel slots of other carriers. Such repositioning accounts for around 1% in total maritime transportation (Table 6.10).

Sensitivity analysis for scenario B

In the scenario with only fuel and handling charges in empty container repositioning cost, the short-term leasing option is economically reasonable only in the situation of inadequate vessel capacity. As a result, the impact of different factors on leasing decisions is analyzed in the situation of reduced capacity for empty container repositioning by 20%. The leasing conditions include the requirement of the minimum lease duration of 3 months and reduced drop-off charges by 20%. The value of influencing parameters are changed by 10%, and the results are analyzed taking into account the effect on total profit from container management (Figure 6.14) and the total number of leased containers (Figure 6.15).

Analysis of leasing decisions and the total profit from container management: Before analyzing the impact of parameters on leasing decisions, certain differences must be pointed out in the current scenario compared to the previous one. Scenario B is characterized by a greater flow of empty containers due to the reduced shipping cost (see Table 6.10). More customers can also be served with empty containers rather than be rejected in service based on a high repositioning cost. As a result, in the situation of high-volume container flow, the limitation of vessel capacity has a much stronger impact on leasing decisions. Even though the short-term leasing is unprofitable here, its share is still high primarily due to the restricted vessel capacity (see Table 6.10). Moreover, the variation in cost of container repositioning does not impact so much on the customer rejection but the leasing decisions.

[7] Leasing conditions include reduced drop-off charges by 10% and no requirement of the minimum lease duration.

Overall, the sensitivity analysis shows the similar relations between parameters and model's results as in the previous scenario A. The greatest potential for optimization is presented in financial factors related to repositioning and storage (Figure 6.14). However, in this scenario, the terminal handling charges make a greater impact than the shipping cost, since the latter includes only variable fuel cost per TEU.

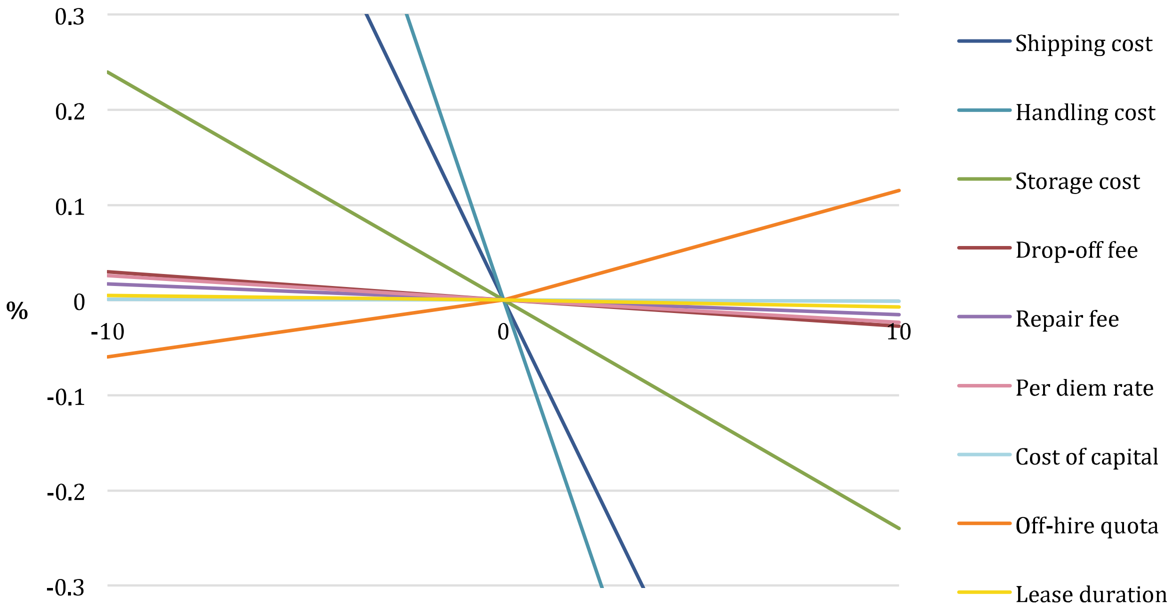

Figure 6.14: Change in the total profit from container management with a change of influencing parameters by 10% (scenario B with limited vessel capacity and reduced drop-off fees by 20%)

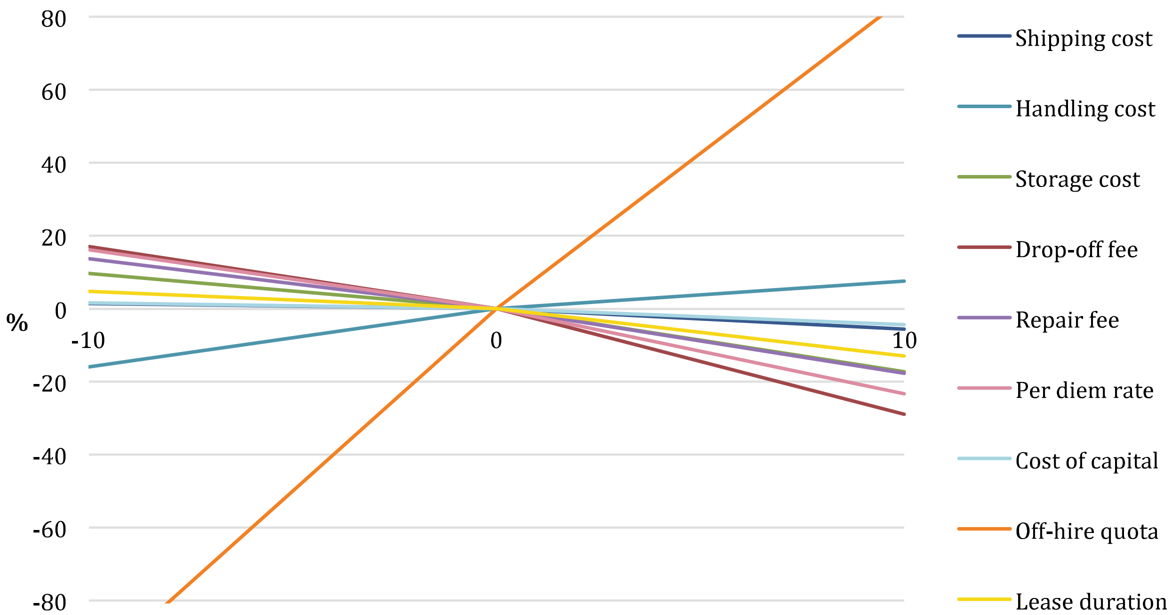

Figure 6.15: Change in the total leased number with a change of influencing parameters by 10% (scenario B with limited vessel capacity and reduced drop-off fees by 20%)

Another difference is a much weaker variation of the leased number as a result of changes in costs. The leased number varies very slightly since the leasing decisions are caused primarily by the limitation of vessel capacity and not by the financial factors (Figure 6.15). Moreover, as was already mentioned before, a share of rejected transport demand in the total shipping volume is fairly stable here. As a result, the increase in repositioning costs does not force a higher rate of customer rejection, but it leads to a slightly higher leased number. The higher the repositioning cost, the greater is the leased number. Whereas the increase in costs in the previous scenario causes, in the first place, a higher rate of unsatisfied transport demand. Consequently, a lower transport volume significantly reduces the necessity of leasing.

Finally, the same as in previous scenario, the off-hire quota belongs to the most influential factors in leasing decisions. Thus, it is the most important factor in the negotiation with leasing companies.

6.4 Summary of results

The results demonstrate that in the given settings, the share of empty container repositioning in the shipping network makes up around 18% of total transportation. This value resembles the statement made by Drewry Shipping Consultants, which estimated a share of global empty container movements as 20% of all maritime container transportation (Drewry Shipping Consultants, 2010).

The results also show that in the given settings the short-term leasing is economically reasonable only in specific and very limited cases: i.e. in the situation of inadequate vessel capacity. The leasing option is not profitable even when the shipping cost of empty containers is very high. The leasing decisions can be considered in the latter case only when more favorable leasing conditions can be negotiated with the lessor, specifically: the drop-off charges are reduced. Based on the interview with individual shipping companies, such results reflect the shipping reality. The possibility of very high off-hire cost (drop-off charge and repair fee) is one of the reasons, why the ocean carriers try to avoid the short-term leasing option. At the same time, it is possible to negotiate no charges for the drop-off of leased equipment. The repair fees can also be set at a minimum guaranteed "flat rate". As a result, the short-term leasing is still applicable in certain cases. However, its number and utilization pattern varies from company to company, depending on the negotiated leasing conditions, previous leasing history of a carrier, and leasing volumes, etc.

In all scenarios, two typical patterns for leased container utilization can be recognized. When no minimum lease duration is required, containers are being on-hired in Asia at the beginning of the planning period, and almost immediately used for specific trips on all shipping routes. Since a large number of the one-way trip lease is prohibited by the lessors, containers are being assigned to the round trips with backhauls to the ports, associated with the most expensive repositioning cost or the greatest repositioning flow. This result is close to reality, as shipping companies tend to on-hire containers in Asian and use them on all routes with the gradual off-hire in all regions.

When the minimum lease duration is required, containers are forced to circle longer in the shipping network. Leased containers can also be stored before the assignment to the next shipments. In both cases, a number of the one-way trip lease is very limited.

The conducted sensitivity analysis shows that the condition of how fast and how many containers can be returned back to the lessor in the container surplus regions plays the most important role in leasing decisions. As a result, the off-hire quota has one of the greatest potentials for profit optimization. This result is also confirmed by the interviews with individual ocean carriers.

Finally, the analysis of results shows that the demand rejection in the situation of inadequate vessel capacity, or in the situation of high empty container repositioning cost can also maximize the total profit from container management in the shipping network. Therefore, this option must be also incorporated into the tactical planning of container management.

Thus, the model enables the evaluation of the leasing decisions in different scenarios. As a result, it can assist the carriers in the negotiation with leasing companies (e.g. in the negotiation of the off-hire quota), and support the tactical decisions on the deployment of leased containers in the shipping network.

The small test instances for the model can be solved with Gurobi 6.5.0 in a reasonable time. However, finding an integer solution to the problem with longer planning periods is much more time-expensive. Therefore, in order to analyze the short-term leasing option in various settings in larger test instances, the model is solved as a relaxed linear program. In another case, the application of heuristic algorithms instead of typical solvers like Gurobi or CPLEX is preferable.

7 Case study for the inland container management

7.1 Study network

7.1.1 Inland service network of an ocean carrier

The case study is focusing on the U.S. Midwest region, which includes the following 12 U.S. states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. According to several studies on U.S. containerized traffic distribution (Levine et al., 2009a; Levine et al. 2009b, Fan et al., 2010; Lee et al., 2012), as well as information on carrier's haulage publicly available at Hapag-Lloyd website (Hapag-Lloyd, 2015), the customer demand for transportation in the area is served mainly as an intermodal shipment using railroad for haulage between a port and an inland terminal, and truck – for the local drayage.

Thus, the inland service network of the case study includes (Figure 7.1):

- 4 port gateway, representing an aggregated group of ports in specific U.S. coast areas (Table 7.1);

- 12 terminals, representing main intermodal facilities in each state of the Midwest region: Minot, Fargo, Minneapolis, Chicago-West, Chicago-East, Omaha, Kansas City, St. Louis, Cincinnati, Columbus, Cleveland, Detroit;
- 10 empty container depots located at the rail terminals;
- 11 import customer locations and 11 export customer locations.

Table 7.1: Ports in the ocean carrier's inland service network

U.S. coast area	Ports	Port node in the network
West-North Coast	Seattle Portland	WC-N
West-South Coast	Oakland LA/LB	WC-S
East-North Coast	New York	EC-N
East-South Coast	Norfolk	EC-S

It must be noted that terminals are not represented in the physical network of the case study. Terminal locations are used only in order to determine an approximate route of import/export intermodal shipments and associated rail and truck transportation distances, times, and costs. Moreover, ocean carriers normally locate their depots in close proximity to the rail yards. As a result, the location of depots can be identified with the position of intermodal terminals.

Each customer location represents an aggregated cluster of import or export customers within a terminal service area, which is approximated by a circle with a radius of 200 miles. Connections in the transport network denote rail haulages between depots as well as truck drayage of empty containers between depots and customer locations. Figure 7.1 demonstrates the transport connections in the network. However, for the sake of network clarity, only certain representative links between nodes are shown.

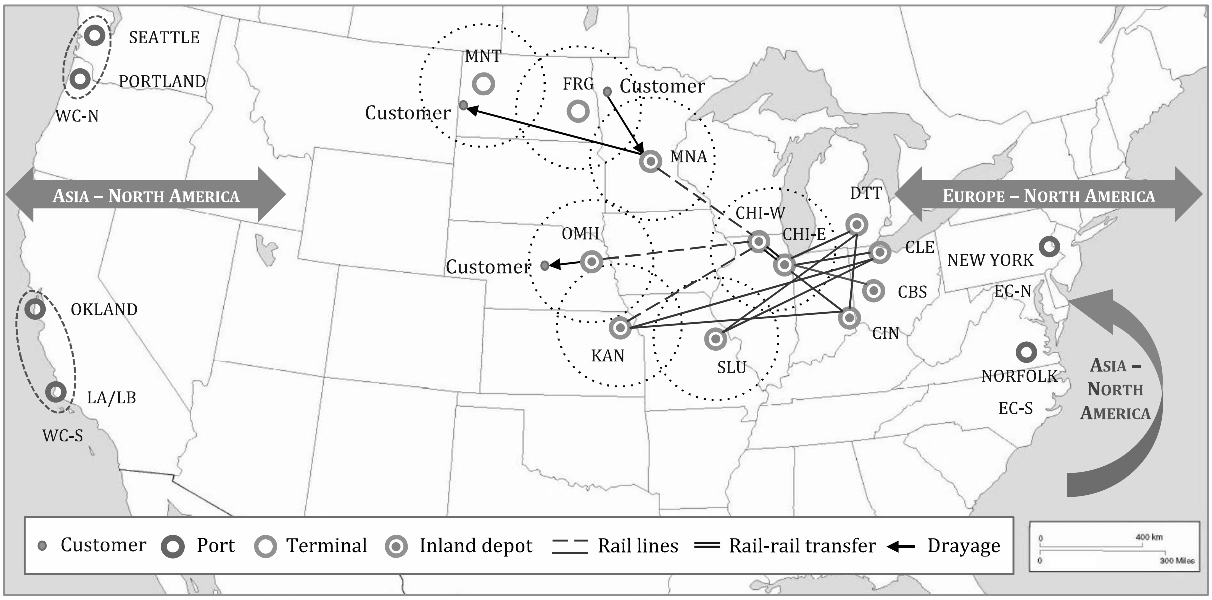

Figure 7.1: Transport network for inland services in the U.S. Midwest region

The pick-up and drop-off of empty equipment can be performed only within service areas of each container depot. Assuming a uniform distribution of customers within a terminal service area, an average distance for the local truck drayage is determined as ⅔ of the radius of an area. This distance coincides with the distance for empty container pick-up and drop-off at depots. There are exceptions, as is the case with customers in Minot and Fargo areas. Since there are no storage facilities at Minot and Fargo terminals, empty containers need to be taken and returned to the closest depot to Minneapolis. Keeping in mind a uniform distribution of customers within each terminal service area, the average distance of such truck haulage can be approximated to the distance between Minot/Fargo and Minneapolis. The calculation of all truck distances is presented in Appendix C.

Inter-depot rail connections within Midwest region are served by 3 main railway companies: Burlington Northern Santa Fe Corporation (BFSN), Norfolk Southern Railway (NS), and CSX Corporation (CSX). The first operates in the western area, while the last two focus on the eastern states. Since NS and CSX offer similar services for the connections in the given case study, no distinctions are made for their links. As a result, two rail sub-networks with a junction in Chicago terminal can be specified. If containers need to be transferred from one railway to another, additional charges are incurred. In order to reflect this situation in the transport network, an extra link can be introduced (Crainic et al., 1990). The terminal in Chicago is, thus, split into two nodes (Chicago-West and Chicago-East), and the link between them represents the rail-rail interchange. Correspondingly, the empty container depot in Chicago is also divided into two sub-depots. In this way, empty boxes can be, for instance, returned to the western depot, if later on, they need to be repositioned out in the western direction. It must be, however, considered that both depots represent a single entity, and thus, the sum of their container inventories is limited by a single storage capacity.

Finally, when converting the physical transport network into a time-space network for the planning horizon of 181 days, the actual schedules of BFSN, NS, and CSX railway companies are considered (BFSN, 2015; NS, 2015; CSX, 2015).

7.1.2 Container traffic and container fleet

There are no detailed statistics on the distribution of container import and export traffic flow in the inland region of the United States. The information on inland traffic available at the level of port authorities can also be fragmented: e.g. presented for only a few inland regions. As a result, the modeling techniques are often used as an alternative approach for the estimation of origin-destination tables for the container import/export flow in the region (Luo and Grigalunas, 2003; Levine and Jones, 2009; Levine et al., 2009; Fan et al., 2010).

In order to determine the total regional container traffic in the thesis, an approach that is similar to the one used in the global traffic analysis is adopted (see Chapter 6.1.3). Certain aspects are also added: i.e. a transloading portion that accounts for a number of shipments that is being transferred from/to the maritime containers in the port instead of the inland region. The distribution of container flow between separate inland locations can be modeled based on the population density in the region (Luo and Grigalunas, 2003). The estimation process is presented in the form of a formula, and described in more details in the following section. All data are gathered for the year 2011.

Import inflow per vessel call: Two main global trade lines are chosen to generate container inflow and outflow into the Midwest region: North America–North Europe and North America–Asia. The latter is routed through the U.S. Coast, and via Panama channel and the U.S. East Coast.

The total flow of import containers on a trade route going through a port gateway to the Midwest region is calculated using the following formula:

$$Q_{port}^{trade} = VCap \cdot g_{port} \cdot MW(1 - TL) \ ,$$

where:
$VCap$ – typical vessel capacity on a trade route;

g_{port} – share of containers on a vessel, destined for a port gateway;

MW – share of containers at a port gateway, destined for the U.S. Midwest region;
TL – share of containers going to the Midwest region, using transloading option at a port.

A share of containers on a vessel destined for a specific port gateway is determined based on the review of typical shipping services and is set considering the number of U.S. ports served by one vessel. For instance, a typical service on transatlantic route includes vessel calls at New York and Norfolk. As a result, the share of containers on a vessel, destined for EC-N port node in the case study, is defined as 0.5. The other input data and the calculation of import container flow are presented in Appendix C Table C.3. For simplicity reasons, as well as considering that the network of inland locations in the given case study is less detailed than in practice, the resulted value of total container inflow on all vessels is reduced and set to 2000 TEU.

Table 7.2: Distribution of the import container inflow to the U.S. Midwest region per vessel call at a port gateways (%)

Trade line	AS-NA		AS-NA		EU-NA		Total import, TEU
Port gateway	WC-S	WC-N	EC-N	EC-S	EC-N	EC-S	
Import flow per vessel call at port[8] (%)	0.31	0.23	0.12	0.12	0.12	0.12	2000

Further on, the total import to the Midwest region is distributed between separate customer locations based on the population density in the customer areas. Such an approach is often used to identify the traffic distribution in the inland region (Luo and Grigalunas, 2003). The statistics on population was taken from publicly available resources of U.S. Census Bureau (U.S. Census Bureau, 2015). The data is gathered for 11 metropolitan statistical areas, which

[8] The sum might not be equal 1 due to rounding error.

can represent the customer clusters in the case study (see Appendix C Table C.2). The resulted distribution of the import flow between customer locations is summarized in Appendix C Table C.3.

It must be noted that based on the review of existing services of carrier's haulage (Hapag-Lloyd, 2015), customer locations are not served from all ports. For instance, customer clusters in Minneapolis, Minot, and Fargo areas are not offered inland services from the ports on the U.S. East Coast. As a result, separate port-inland location pairs are removed from the range of shipments.

Export flow per vessel call: Customer demand for export haulage is defined based on the estimated value of import shipments taking into account the imbalance rate on each specific trade line: 0.47 on the Asia–North America route and 0.82 on the Europe–North America route (Rodrigue et al., 2011)

According to several studies on container availability, specific states in the U.S. Midwest region, specifically Minnesota and North/South Dakota among others, always experience the shortage of empty equipment (USDA, 2011-2014; Stewart et al., 2013; Minnesota Department of Agriculture and Wilbur Smith Associates, 2008). In order to simulate this scenario in the case study, specific demands for export shipment are adjusted. Final results are presented in Appendix C Table C.4.

Demand for inland haulage in a dynamic network: Presented above export/import distribution is used to generate demand for inland haulage in the dynamic time-space network with a planning horizon of 181 days. In this case, the ship's arrival and departure schedules are taken into consideration (Maersk Line, 2015). Demand for inland import haulage appears in a time moment when a vessel calls at a port. Demand for inland export haulage occurs before the departure of a vessel, considering the time of needed transportation to the port. Delivery time of inland haulages is explained later in the chapter.

Finally, a portion of emptied import containers that can be transported directly from import to export customers within the depot service area (street-turn from consignee) is set to 5% (Wolff, 2012, p 22). A portion of container demand at the export customer location that can be met by direct transport from import customer (street-turn to shipper) is calculated as a street-turn from consignee divided by export demand.

Container inventory: The total number of containers available at ocean carrier's inland depots at the beginning of planning horizon is set to a value of total export per vessel call at all port gateways – 1207 TEU. Initial container inventory in each separate storage facility equals the export demand in a depot service area. At the same time, container inventory in Minneapolis depot equals the export demand in 3 areas: Minneapolis, Fargo, and Minot.

7.1.3 Rates and delivery times for the shipments

Rates for the export and import shipments include the inland rates for the land leg and freight rates for the sea leg. All data are estimated based on the publicly available resources for the year 2011.

Freight rates and average profit from shipment on a trade route: All-In-Rates for maritime shipment on Asia–North America and Europe–North America routes for east- and westbound directions are determined based on Drewry Research (2011) and presented in Table 6.6 in previous Chapter 6. These freight rates are then used to define an average profit from import/export shipment on a specific trade line. The procedure for calculation is as follows:

- Estimate the number of containers carried on a vessel in head-/backhaul on a trade route as:
  Typical vessel capacity on a route × Load factor for the vessel × Imbalance rate (only for back-haulage);
- Estimate an average revenue from head-/backhaul on specific trade route as:
  Freight rate × Number of containers on a vessel;
- Estimate an average cost from head-/backhaul on a route as:
  Cost of a vessel slot × Nominal vessel capacity;
- Estimate an average profit per TEU as: (Revenue – Cost) / Nominal vessel capacity;

All input data and the results of calculation are explained in Appendix C Table C.5, and the results are summarized in Table 7.3.

Table 7.3: Average profit from import and export shipments on trade routes

Trade line	Asia–North America		Europe–North America	
Direction	Eastbound	Westbound	Eastbound	Westbound
Profit ($/TEU)	1163	23	-522	1141

Inland rates: The carrier's haulage rate for the intermodal shipment could not be obtained from the publicly available resources for all port-inland location pairs in the case study. Therefore, in order to enable the consistency of all data, the inland tariffs are estimated using the following formula:

$$\left(Rate_{Rail}L_{Rail} + Rate_{Truck}2L_{Truck}\right)FS \ ,$$

where:

$Rate_{Rail}$ – rail rate for haulage between a port and an intermodal terminal ($/TEU/mile);

L_{Rail} – distance of rail haulage between a port and an intermodal terminal (mile);

$Rate_{Truck}$ – truck rate for local drayage from/to an intermodal terminal ($/mile);

$2L_{Truck}$ – round trip distance for local container drayage (mile);

FS – fuel surcharge applied to the intermodal tariff by the ocean carriers.

The rail rates and the rail distances are determined using the STB Public Waybill Sample from the U.S. Department of Transport (U.S. Surface Transportation Board, 2011). The waybill gives the information about origin and destination, charges, rail revenues, shipment type, etc. It must also be noted that the reported rail revenue already includes the handling charges, and thus, no handling fees are added to the formula. The data in the waybill 2011 was selected using following criteria:

- Intermodal commodity or mixed freight shipments: code STCC 46;
- Type of a rail car: COFC/TOFC[9];
- Type of a unit on a rail car: container;
- Car ownership: railroad;
- Container ownership: private;
- Weight of a shipment: max. 23 tons for TEU including the weight of container;
- Type of move: import/export;
- Transportation service: from rail ramp to rail ramp.

As a result, the rail rate is set to be $0.7 per container-mile.

The truck rate for 2011 is estimated to be $1.6 per mile (Fender and Pierce, 2012; TransCore, 2011). It must be noted that the fuel surcharges are not included in the rate but added to the total fuel surcharge when charged by the ocean carrier. The distance of the local drayage within a terminal service area is set to 160 miles (for the formula explanation see Appendix III).

Inland fuel surcharge for carrier's haulage typically has a form of a fixed charge added to the inland rate or a form of a percent applied to the cost of every inland move. It may vary for different shipping lines and the direction of the inland haulage. For simplicity reasons, the fuel surcharge in the case study takes a form of a percent applied to the cost of every inland move and is calculated according to the generalized formula offered by the Transpacific Stabilization Agreement (TSA, 2015). Using an average HDF[10] price of $3.84 per gallon for 2011, the fuel surcharge is calculated as 32.5%.

Finally, it must also be noted that the inland rates of import and export shipments are typically imbalanced. As a result, the calculated tariffs are adjusted based on the review of inland haulages available at Hapag-Lloyd website (Hapag-Lloyd, 2015). Due to space reasons, the results are presented in Appendix C Table C.5 and Table C.6.

Delivery time: The average transit times for intermodal movements between ports and inland locations are set using the study of Prince et al. (2005), as well as the review of existing

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[9] COFC/TOFC – container on flat car/truck on flat car
[10] On-Highway Diesel Fuel

shipping schedules offered by CSX, NS, BNFS, and UP railway companies. In the study, an extra day is added to the rail transit time to account for the local delivery time. In specific cases, an extra day or two is also added based on experts' experience. Delivery times for inland shipment are summarized in Appendix C Table C.8.

7.1.4 Costs and times

The cost of global empty container repositioning: Repositioning cost of empty containers out of the North American region includes only terminal handling charges (THC) on both sides of the global route. For simplicity, it is assumed that empty containers are shipped using free capacity on carrier's own vessels, and thus, no transportation cost on the sea is applied. Based on the review of handling charges in the previous chapter (see Table 6.7), the cost of empty container repositioning used in the case study is presented in Table 7.4. It must be noted that the handling charges are reduced since the ocean carrier typically negotiates a certain discount with the terminals (see Chapter 6.1.3).

Table 7.4: Cost of global empty container repositioning out the North American region

Trade line	Asia–North America		Europe–North America
	From West Coast	From East Coast	
Cost ($/TEU)	530	650	540

Cost and time of rail haulage: The rail rate charged for container transportation is calculated using the following formula:

$$Rate_{Rail} L_{Rail} FS_{Rail} D\ ,$$

where:

$Rate_{Rail}$ – rail rate for haulage between rail ramps ($/TEU/mile);

L_{Rail} – distance between rail ramps (mile);

FS_{Rail} – fuel surcharge applied to the rail rate by railway companies;

D – contract discount for large ocean carriers.

The rail rates and the rail distances between particular rail ramps are again determined using the STB Public Waybill Sample for 2011. The rail revenue per ton-mile reported in public documents typically varies with distance and weight of a shipment. A lower price for long-distance shipments is caused partially by the absorption of the handling charges in the total rate. The same shipment with the same handling charge but for a shorter distance results in much higher revenue per ton-mile (Prater and O'Neil, 2014). Review of rail rates shows, for example, that the short-distance shipments in 2011 were 1.5 times the average rail rate and around 2 times the rate for the same shipment over the long distance (> 500 miles).

As a result, the rail rate for haulage between inland terminals and the ports is used as previously determined – $0.7 per container-mile. However, the regional shipping between rail ramps within the Midwest region has a distance range of 500-600 miles, and, therefore, charged with a higher rate – $1.4 per container-mile.

Fuel surcharge, which is added to the final rates by the railway companies, is calculated as a percent to a line-haul freight rate for a certain increase in fuel price above the base level or applied using mileage-based surcharge programs for certain rail services. It also varies from a railroad to a railroad taking into account different fuel efficiencies. Using publicly available data from 2011 (CN, 2015), the average fuel surcharge for the rail rates in the case study is set to 27%.

Ocean carriers usually have special price programs due to the operation with high container volumes. Such policy enables obtaining lower rail rates than stated in the public documents. Due to confidentiality of such data and specific conditions in each separate case, it is fairly complicated to obtain the data on such discounts. According to the analysis of LaGore (2014), the shippers can get, for instance, a 10%-reduction with the contracted rate or sometimes even more. Considering that the rates are being estimated for large ocean carriers, a higher discount is used in the case study, namely – 15 %.

Finally, ocean carriers typically get a substantial reduction in price for the repositioning of empty containers on main rail corridors towards the port direction. The price reduction can range from 30% to 50% depending on a direction, a carrier, and a volume, among others. As a result, the rail rates for empty containers on connection “depot-port” are corrected using a 0.5 factor. Later on, the behavior of the model is also analyzed with different discount values. Calculated rail costs are presented in Appendix C Table C.9.

It must be noted that the given transport network also contains a link that represents the transfer of container between railroads. The cost of the link is set to $250 taking into account publicly available data on the rail-rail interchange charges.

The transit times for rail haulage between rail ramps are analyzed using the existing shipping schedules offered by CSX, NS, BNFS, and UP railways, and the derived data is added to Table C.9.

Cost and time of truck drayage: The cost of truck movements are calculated based on the average trucking distance (see Appendix C), and the average trucking cost per mile, which is estimated for 2011 as $2.03 per mile including fuel surcharge (Fender and Pierce, 2012; TransCore, 2011). The results are presented in Appendix C Table C.9.

The drayage time in the given transport network is analyzed taking into account the following aspects: a trucking distance, an average trucking speed of 50 miles per hour, the 14-hours limit on the on-duty time for drivers set by Federal Motor Carrier Safety Administration (FMCSA, 2015), and an additional waiting time at customer locations (typically 3 hours). Based on the performed analysis, most of the customers need an extra day for the round-trip drayage. This time was already added to the delivery time of every shipment. Therefore, the time of the link associated with container pick-up/drop-off is set to 0. The exception is the customers in Minot area, which need an additional 2 days due to the longer drayage of containers from/to the terminal in Minneapolis. In this case, the time of the link associated with pick-up/drop-off of empty containers is set to 1 day.

The total cost of inland haulage for ocean carrier: Every demand for carrier's haulage is characterized in the mode by the inland rate charged from customers and its actual cost for the shipping line. The total cost is calculated using data presented above, and applying the following formula:

$$Rate_{Rail}L_{Rail}FS_{Rail}D + Rate_{Truck}L_{Truck}\ ,$$

where the first component of the sum represents the cost of the rail haulage including all additional charges, and the second component represents the truck drayage of import/export container including the fuel surcharge. The cost of empty container pick-up and drop-off is not included into the total cost but is considered separately in the proposed model in order to account for different options of delivery. The data is presented in Appendix C Table C.7.

Storage cost: Storage cost of an empty container in inland depots is set to $1 per day while the cost of $2 per day applied in the ports (Davis, 2011).

7.1.5 Capacities

Storage capacity in the ports is set as 2 times the total weekly surplus of container inflow into the Midwest area. At the same time, inland depots in the case study can store the container surplus and the emptied import containers before their reassignment to the export customers. As a result, the storage capacity in inland depots is set as 2 times the weekly import flow in the terminal/depot service area.

Vessel capacity for empty container repositioning out of a port gateway on a trade line is set as a difference between import flow and export flow per vessel. Then, if at a certain time moment there is a vessel departure planned, the vessel capacity takes a certain calculated number, otherwise, it equals 0. The input data related to capacity is presented in Appendix C Table C.10 and Table C.11.

7.2 Basic scenario

The case study has a purpose of testing the model and analyzing the strategy of inland service limitation in a situation of high repositioning cost for empty containers. In order to mitigate the effect of raising costs, an ocean carrier can correspondingly raise its inland rates. However, in order to analyze the proposed strategy, the basis scenario assumes constant freight rates – i.e. there is no increase in freight rates with the purpose to pass the high cost of empty container repositioning on customers.

The other assumptions of input data for the case study include:

- 50%-discount on rail haulage of empty container in a port direction;
- Averaged cost of empty container repositioning from a port on a global route;
- Adequate vessel capacity since its reduction results in the infeasibility of the model;
- Average inland turn-around time of import containers in the inland region – 2 weeks (14 days);
- Return of all unused empty container surplus back to the port area in 1 week (7 days)

7.3 Result interpretation

7.3.1 Computational time

The model with all scenarios is created in AMPL (A Mathematical Programming Language) format and solved using Gurobi 6.5.0 (Gurobi Optimization, 2015), running on a 16 GB 2.5 GHz Intel Core i5 computer. The computational efficiency of the solver applied to the model as an integer (IP) and a linear (LP) program is shown in Table 7.5. Results show that Gurobi solver enables a good performance of the Inland Model in a reasonable time.

Table 7.5: Computational time (CPU) for test instances of Inland Model with different planning horizons solved by Gurobi

Horizon (months)	Time periods (days)	Number of variables	Number of constraints	CPU time (sec) for IP	CPU time (sec) for LP	Optimality gap (%)
1	30	7718	6873	0.20	0.07	0
3	90	22047	19789	1.39	1.08	0
6	181	43504	39062	5.50	4.27	0
12	362	87127	78347	41.32	23.17	0

7.3.2 Validation process

Validation methodology was already described in Chapter 6.3.2. It was also already mentioned that the validation by results is associated with some difficulties in the current study.

Firstly, the model presents the strategy of rejecting certain customer demands for inland shipping under the ocean carrier's Through Bill of Lading. In this way, a shipping company can limit its inland transport services for certain inland locations or customer clusters. However, it is rather difficult to validate a strategy or a tactic with the historical data, since there is no extensive amount of accumulated information about it yet. Moreover, in our case, not all carriers have been limiting their inland services in the North American region.

Secondly, any data about inland container volumes are also associated with a high level of confidentiality. As a result, it is not possible to present the tables with real data for its comparison with the results of the proposed model.

In order to validate the model, we use publicly available information about ocean carrier's inland services as well as the analysis of some shipping experts. For example, after announcing the intention to reduce the inland service network in North America, Maersk Line presented a map of its revised inland services on the company's website (Maersk Line, 2016). Additionally, the model is tested in different scenarios in order to analyze its behavior in various settings and to study its sensitivity to different factors.

The following sections describe the results of the Inland Model in different settings to demonstrate the model's "appropriateness" against the real practices while taking into account the assumptions and simplifications made in the modeling process. The references to the Maersk Line inland service network are provided throughout the description of the model's results.

7.3.3 General results of inland container management

Results of the model show that the option of inland service reduction introduces a certain potential for optimization in inland container management in given settings. Restriction of inland services is particularly reasonable in the situation when no increase in freight rates is considered as compensation for the increased cost of empty container movements.

According to the model's assumptions, all accumulated container surplus must be eventually shipped out of the inland region and thus is associated with a repositioning cost, both on sea and land. In the basic scenario without inland service limitation, a major share of empty containers is accumulated in Chicago region, followed by Michigan (Detroit) and Ohio (Cincinnati, Columbus, Cleveland) states (see Figure 7.2). Since ports of the West Coast have much higher shipping capacities, a major share (almost 60%) of the total container surplus in the Midwest region is returned to the West Coast. Empty container flow comes predominantly from Chicago. The rest of the surplus is relocated from the eastern part of the region to the East Coast ports. Furthermore, since the region has certain areas with container shortage, a small portion of empty containers in Chicago and Detroit is assigned to the inter-depot repositioning.

Due to the prevailing portion of empty container flow on the long-distance routes to the West Coast, the total repositioning cost represents a relatively high value. Moreover, while the carriers can negotiate a reduced price for rail haulages in the direction towards the ports, there are typically no substantial discounts for the empty container movement between depots. As a result, in the situation of unchanging freight rates, it becomes reasonable to limit a small portion (1.4%) of import haulages to the Midwest region regardless of a possible loss of customer orders on the whole shipping chain. The restriction of import orders enables to reduce the surplus of empty containers in the region by 4% and thus to cut down the unproductive empty container movements at carrier's cost. Table 7.6 demonstrates that the decline in the total repositioning cost including the storage cost of container surpluses in the region out-weights the loss in profit from the rejected shipments, and brings even though slight but positive effect in container management. The detailed result about the change in financial factors resulted from the service restriction is presented in Appendix B Table B.1.

Table 7.6: Absolut change in financial parameters due to the inland service restriction ($ million)

Parameters	Change	Parameters	Change
Cost of repositioning, sea leg	-0.73	*Profit from shipments, sea leg*	-1.53
Container management cost, inland leg	-1.53	*Profit from shipments, inland leg*	-0.68
Total cost of container management	-2.26	Total profit from shipments	-2.25

Optimization effect (Saving) = $**0.01 million**

Inland service restriction = **1.4%** of import demand

It must be noted that the results of the model correspond with the real-world practices of certain ocean carriers, which has started limiting their inland haulage services in the North American region (Maersk Line, 2007; Stewart et al., 2013, p. 6; Clott et al., 2015). However, in order to be able to make any statements about the actual savings or a precise optimization affect, the adoption of the model into the ocean carrier's operations must take place. Thus, the model's results can prove only the effectiveness of the strategy in a given setting.

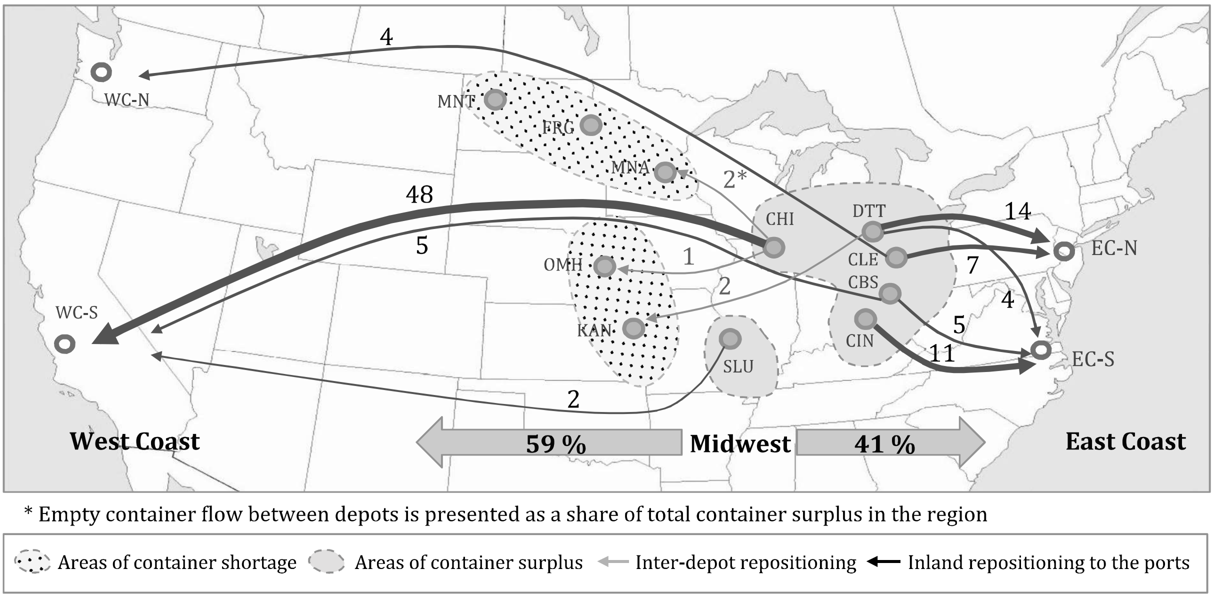


Figure 7.2: Distribution of empty container flow in the region in scenario without inland service restrictioin (%)

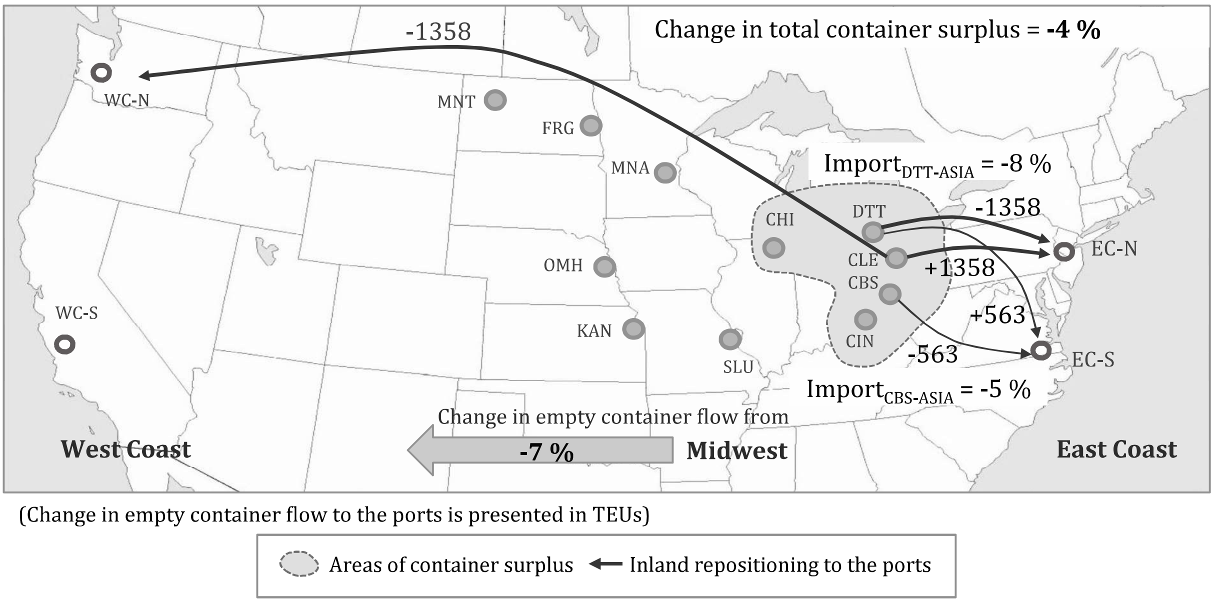


Figure 7.3: Inland service restriction and the change in empty container flow

The further analysis shows that, in the given setting, inland haulages are restricted for the global shipments from Asia to Detroit and Columbus (Figure 7.3). The Asia–North America route is typically less profitable than the transatlantic route due to the high volatility of container traffic and significant flow imbalance there. Moreover, empty container repositioning from the Midwest region of North America to Asia, especially including the long-distance inland haulage to the West Coast ports, is associated with a higher cost than repositioning to Europe. In this way, the reduction of the container surplus in Detroit and Columbus does not only decrease the empty container flow to Asia but also enables the inland repositioning to the West Coast ports to be avoided, particularly to the northern ports of the West Coast.

It should be noted that the case study assumes a direct relationship between the profit from the inland haulage and distance. In a specific ocean carrier's case, the knowledge of carrier's exclusive rates and pricing policies is, however, required in order to get a more precise result. At the same time, despite the simplifications, the proposed Inland Model can still provide the results that correspond with a real practice of the inland service restriction adopted, for example, by Maersk Line. Based on the information about Maersk Line's revised inland haulage services (Maersk Line, 2016), the customers located in Michigan and Ohio states are no longer provided with the carrier's haulages from/to the gateway port of Seattle.

7.3.4 Effect of repositioning cost on inland service restriction

Decisions on the inland service restriction in the Midwest region of North America depend directly on the cost of empty container repositioning. The higher the cost, the greater is the optimization potential of the proposed strategy.

The cost of repositioning on the inland leg: As was previously discussed, an ocean carrier typically does not pay a full price for rail haulage of empty containers but negotiates a certain discount for rail haulages of empty surpluses towards a port direction. The smaller the discount, the greater is the cost of empty container repositioning in the inland. As a result, the total profit from container management in the case study declines. In order to avoid a strong decrease in the total profit, the restriction of inland services for the import shipments becomes stronger since such action enables avoiding a portion of long-distance haulages of empty containers to the West Coast ports (Figure 7.4). Table 7.7 demonstrates that the flow of empty containers is cut down primarily in the direction to the northern ports on the West Coast, which is characterized by the highest inland rates for repositioning. At the same time, a larger discount for the rail haulage of empty containers (e.g. 55% in the given setting) reduces the financial weight for inland empty container repositioning to the West Coast and thus eliminates the need to limit inland services for import shipments.

It must also be noted that the given case study contains a portion of unprofitable export orders that originate in container shortage areas and require constant inter-depot repositioning with a purpose of inventory balancing. Such shipments are served in the model in order to get at least some contribution to the total container repositioning cost on land and sea. However, when a substantial discount (e.g. 60% in the given setting) can be negotiated for the inland rail repositioning in the direction of ports, it becomes reasonable to ship more empty containers at carrier's own cost, rather than serve all orders for the export haulages originated in container shortage areas. As a result, the reduction in the repositioning cost above the equilibrium point leads to the rejection of some export demands with a purpose of profit maximization (Figure 7.4).

In the given settings, inland services are limited for export shipments from Kansas to Asia through the East Coast ports (Figure 7.5). These shipments are less profitable in the case study. Moreover, empty containers that are not reused for export can also be shipped to the East Cost for the further global repositioning using the vessel capacity of rejected export orders (Table 7.7).

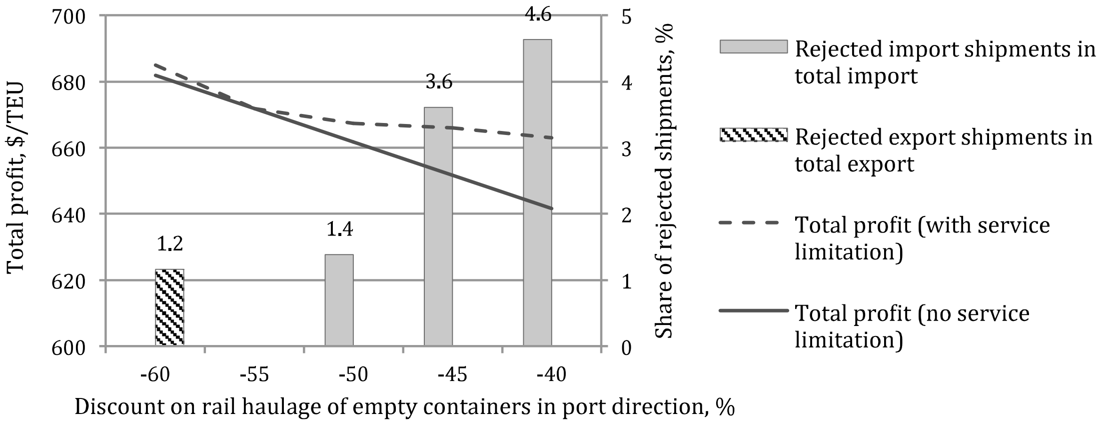


Figure 7.4: Total profit from container management per TEU as a function of inland repositioning cost in scenarios with and without inland service restriction

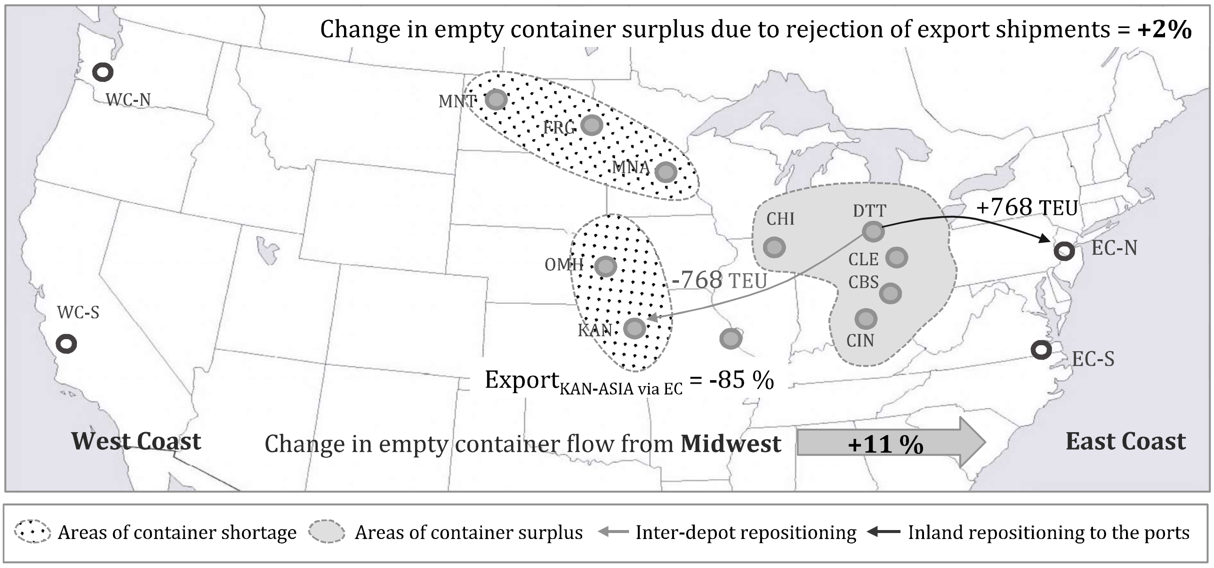


Figure 7.5: Inland service restriction as a result of reduced inland repositioning costs (60%-discount)

Table 7.7: Distribution of inland empty container flow between the ports as a result of varying inland repositioning cost (scenario with service restriction)

Discount for rail haulage of empty containers	Distribution of empty container flow to the ports (%)			
	WC-N	WC-S	EC-N	EC-S
-60%	4	54	22	20
-55%	4	55	20	20
-50%	0	57	21	21
-45%	0	54	23	23
-40%	0	52	24	24

Note: The sum might differ from 100% due to the rounding error.

The presented results demonstrate the realistic behavior of the model. Basing on the information about Maersk Line's revised inland transport services as well as some experts' opinion, export customers in the eastern region of the U.S. Midwest – particularly, in Kansas and Iowa – suffer from the reduction of ocean carriers' inland services from their location to the East Coast ports (Stewart et al., 2013; Maersk Line, 2016).

The cost of repositioning on the sea leg: The impact of inland and maritime factors on repositioning cost is similar. The optimization potential of inland service restriction becomes weaker as a cost is reduced. For example, the decline in the sea shipping cost for empty containers by 5 % enables keeping the whole network of inland services without any restrictions (Figure 7.6). With a further decline in the cost, a small portion of inland services is limited for export locations in container shortage areas with a purpose of avoiding the unproductive inter-depot container movements.

It must be noted that in the given basic scenario an average tariff for the inland repositioning is higher than the cost of repositioning on the sea leg. As a result, a 10%-increase in the inland cost leads to a higher total shipping cost than a 10%-raise in its maritime component. Correspondingly, the inland service restriction for import gets also stronger in the first case in order to have an additionally cut-down of the high repositioning costs. At the same time, a 10%-reduction in inland tariff can lower the total shipping cost much more than a 10%-decline in its maritime component. As a result, there is less incentives for inland service limitation in the situation with a reduced repositioning cost on the inlan leg. The influence of the inland and sea shipping cost on the proposed strategy is demonstrated in Figure 7.7.

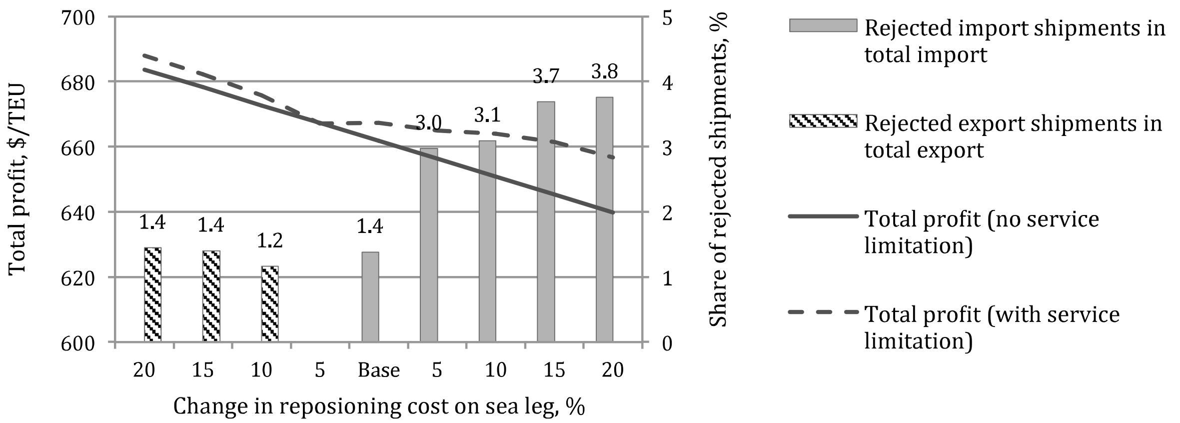


Figure 7.6: Total profit from container management per TEU as a function of global repositioning cost in scenarios with and without inland service restriction

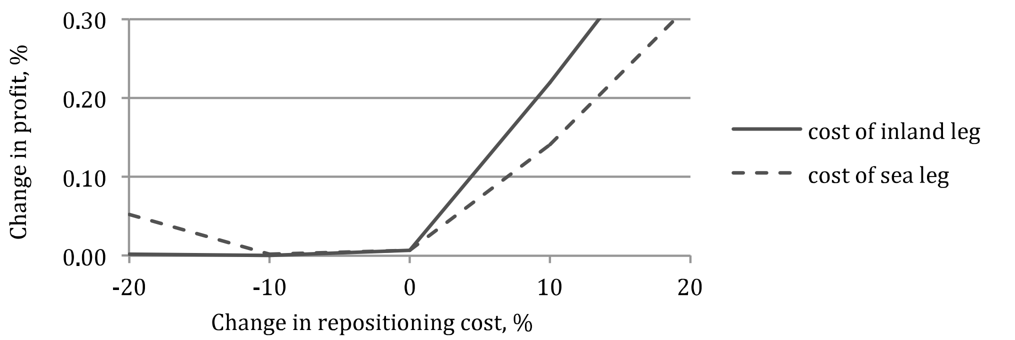


Figure 7.7: Impact of the strategy of inland service restriction on the total profit from container management with a different repositioning cost (%)

7.3.5 Effect of vessel capacity on inland service restriction

The main purpose of inland service restriction in the given scenario is to cut the cost of repositioning from the Midwest region to the West Coast ports. In this situation, the increase of vessel capacity on the East Coast enables a portion of empty container flow to be redirected to Asia through the East Coast ports (Table 7.8). Even though the cost of repositioning on this sea leg is higher, an additional profit from the less restricted import shipments, as well as the savings from the shorter inland haulages of empty containers to the East Coast lead to the higher total profit (Figure 7.8). Finally, the increase of vessel capacity on the U.S. East Coast-Asia sea leg by 40% or up to the Post-Panamax size (10000 TEU) eliminates the need for inland service restriction in the given basic scenario.

The described results demonstrate the realistic behavior of the model. In the real-world shipping operation, numerous discussions are carried out concerning potential effects of increasing the vessel capacity on the all-water transpacific route to the East Coast ports (NCDT, 2012; Dekker, 2014; Tirschwell, 2015).

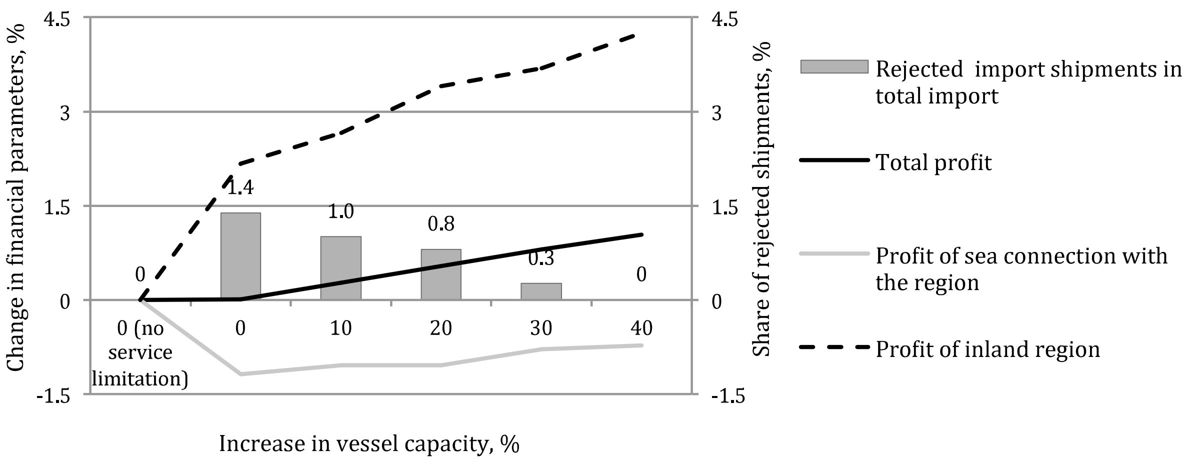


Figure 7.8: Change in financial parameters due to the increase in vessel capacity in scenario with inland service restriction

Table 7.8: Distribution of inland empty container flow between the ports in the situation of increased vessel capacity (scenario with service restriction)

Change in vessel capacity	Change in empty container flow to the ports (%)	
	West Coast ports	East Coast ports
Base	57	43
10%	55	45
20%	52	48
30%	50	50
40%	47	53

7.4 Summary of results

The Inland Model is tested for the Midwest region of North America, which includes areas with container surplus and shortage. The large quantities of unmatched containers result in a high repositioning cost both on the sea and land leg, while the lack of containers in certain areas forces unproductive empty container movements between inland depots, and makes the respective export shipments much less profitable. The raising inland rates for empty containers lead to a corresponding increase in the inland rates. However, in a highly competitive shipping environment, this might not always be the solution. In this case, an ocean carrier can choose to revise the network of its inland transport services.

Developed Inland Model optimizes the inland container management considering an option of rejecting the demands of certain customer clusters for ocean carrier's inland services. Results show that this strategy introduces a certain potential for optimization. Limitation of inland services for certain import shipments avoids the long-distance inland haulages of empty container surpluses to the West Coast ports, while the restriction of inland services for certain export shipments avoids the unproductive inter-depot repositioning to the areas with container shortage.

The model's results also resemble with the real-world practices of certain ocean carriers, which limit their inland service in the Midwest region of North America. Basing on the information about Maersk Line's revised inland transport services, the shipments going through the Seattle port gateway are no longer provided to the customers located in Michigan and Ohio. At the same time, export customers in Kansas and Iowa – the areas with empty container shortage – suffer from the reduction of ocean carriers' inland services from their location to the East Coast ports.

Decisions on inland service restriction directly depend on the repositioning cost for empty containers. The higher the cost, the greater the financial weight of empty container repositioning back to the West Coast ports and thus the stronger is the limitation of inland haulages for the import shipment. In the situation, when an average inland rate represents a greater portion of the total shipping cost, the increase in the inland rates has correspondingly a greater influence on decisions about the service reduction. At the same time, the decrease in a maritime component of the cost effects in a greater way the inland service restriction for export customers.

Finally, the increase of the vessel capacity for repositioning to Asia from the East Coast ports represents an alternative to the proposed strategy. Such results also demonstrate the realistic behavior of the model. Numerous discussions are carried out in the real shipping world regarding the potential effects of the increase of the vessel capacity on the all-water transpacific route to the East Coast ports.

Thus, the model produces appropriate results compared to the real-world practices. However, the knowledge of rates and costs of individual carriers is required in order to analyze the optimization strategy in the individual inland service networks. Moreover, it order to be able to make any statements about the actual savings or the actual optimization effects, the adoption of the model into the ocean carrier's operations must take place.

8 Connection between models through container travel time in inland

8.1 Coherence between results of the Maritime and Inland Models

Container turn-around time in the inland region is the main parameter that enables the consistent results of container management in ocean carrier's maritime and inland service networks. The current section uses the results of the case studies from previous chapters to demonstrate the connection between models' outputs. It must be, however, noted that the Maritime and Inland Models are tested using different values of planning horizons. Therefore, the corresponding results cannot be summed up here.

Suppose a carrier wants to get a picture of the global container management and its profit with a shorter turn-around time of containers in the U.S. inland region. Having provided the average data on transport demand and the time that containers spend in the U.S. region, the Maritime Model can determine a magnitude of the global empty container repositioning and present the total profit from the corresponding management (P_M). The developed Inland Model can determine the profit from inland container management having as input data the demand for inland haulages and the same restriction of an average container turn-around time in the U.S inland region. Figure 8.1 demonstrates, for instance, the change of the total profit from container management in the U.S. Midwest region (P_{US}) with different restrictions of total inland time. It also shows that in the cases when not all customers can be provided with inland services within a given time window, a potential financial effect on the corresponding sea shipping can be determined. An average loss of profit on the sea connection with the region (ΔP_{SEA_US}) is defined as a difference between the profit from sea shipping, when all transport demand is satisfied, and the profit when certain customers are rejected. For example, in the given case study, the average container turn-around time of 10 days (1.4 weeks) requires the significant restriction of ocean carrier's inland haulages and might lead to around \$5.6 million of lost profit on sea legs during the ½-year of operation. This result can be then used to correct the total profit from the global container management, obtained by the Maritime Model for the same value of inland travel time in the U.S. region.

It must be noted that, when an ocean carrier cuts down a number of customer locations served, it does not necessarily mean losing the customers for the shipping on the sea legs. Affected customers might still ship their cargo with the carrier but use either transloading option or an option of the merchant's haulage for inland movements. However, when making decisions on the restriction of inland services, the possibility of a lost profit on the whole transport chain should be still considered.

In addition to the lost profit, the rejection of export customers increases the surplus of empty containers, which must be then repositioned globally at carrier's cost. For example, the limitation of average container turn-around time in the U.S. Midwest region to 10 days (1.4 weeks) leads to the inland service restriction primarily for export shipments. As a result, the magnitude of empty container repositioning increases by more than 11% (Table 8.1). This result does not represent, however, an actual repositioning in the global shipping network, but only reflects the changes in the regional surplus of empty containers and the associated with it average cost of inland and maritime repositioning to the regions with container shortage.

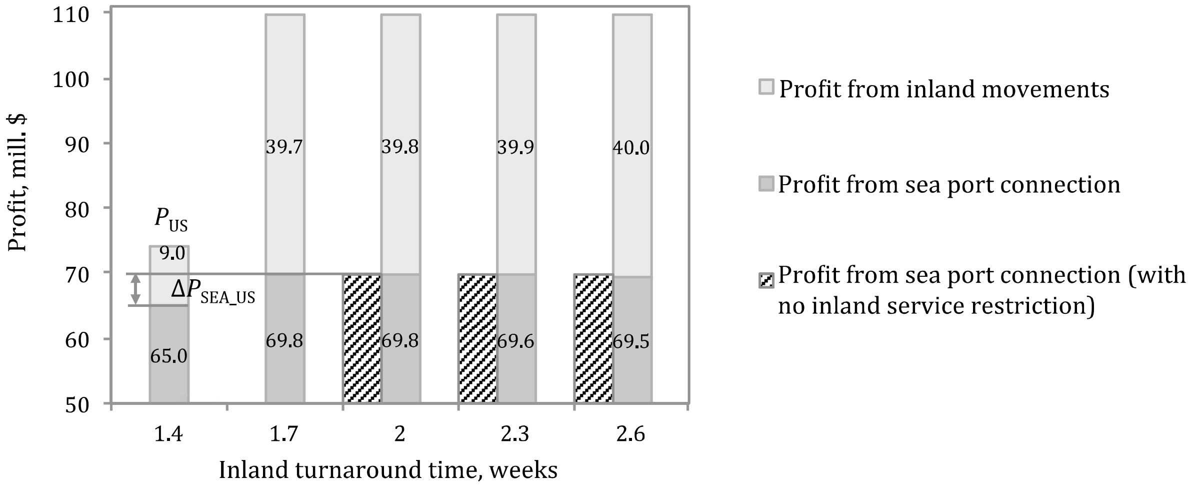


Figure 8.1: Profit from inland container management including an average profit from seaport connection with the inland region

Table 8.1: Change in selected parameters due to the inland service restriction in scenario with container turn-around time of 1.4 weeks

Parameters	Value
Rejected import shipments in the total demand	5 %
Rejected export shipments in the total demand	7 %
Change in the total profit from the seaport connection with the inland region	- $5.6 million
– Lost profit from the shipments on the sea legs	- $3.1 million
– Cost of empty container repositioning out of the region	+ $2.5 million
Change in the volume of empty container repositioning	+ 11%

A more detailed explanation of results of maritime and inland container management with different values of container turn-around time in the region is presented in the following sections.

8.2 Effect of inland turn-around time restriction on inland container management

Using container turn-around time in the region as a control parameter, an ocean carrier can influence, how far its equipment can go into the hinterland, and how fast it must be returned to the port. These decisions directly affect an ocean carrier's services on the inland and sea legs, as well as the associated total profit from container management (see Figure 8.2).

When initial average turn-around time of containers is enough to satisfy all demand for inland haulages (e.g. it equals 2 weeks in the given setting), the increase in inland time leads only to the growth of total storage costs, which negatively affects the profit results. It must be noted that inland transport network is already characterized by a high empty container repositioning cost. As a result, certain inland haulages for import shipments are restricted in order to avoid the repositioning of unmatched empty container surplus back to the ports (see previous Section 7.3). With the increase in container turn-around time, the number of restricted inland services is correspondingly growing in order to mitigate the rising storage cost with at least some cost savings in the repositioning (Table 8.2). The results about the change in financial parameters are presented in Appendix B Table B.2.

In the situation when an average container turn-around time in the region is not enough to serve all demands for inland haulages, the model defines, which customers should be rejected, and provides a maximum possible profit with the given time restrictions. In the current case study, inland services are limited only for the shipment on the North America-Asia trade route because of the least freight rates there. The transport services are also restricted predominantly for export shipments since the reuse of empty containers after the import delivery increases the total turn-around time (Figure 8.3).

The main customer groups with limited inland services are located in the hard-to-reach areas with container shortage: e.g. Minnesota, North Dakota or Nebraska states. These areas are associated with the longest transportation time in the given network. For instance, the shipments from Minneapolis as well as Omaha/Kansas City areas to the U.S. West Coast are routed through Chicago terminal and thus can take up to 9 days without consideration any delays in the transport process. Moreover, these customer locations require an additional repositioning of empty containers into the area from other depots, which also increases the total container turn-around time.

Finally, certain import customers import customers in container surplus area in Ohio also get the restricted inland haulages from the U.S. West Coast ports. In this way, the model aims to limit the long round trips with the most expensive empty back-haulages.

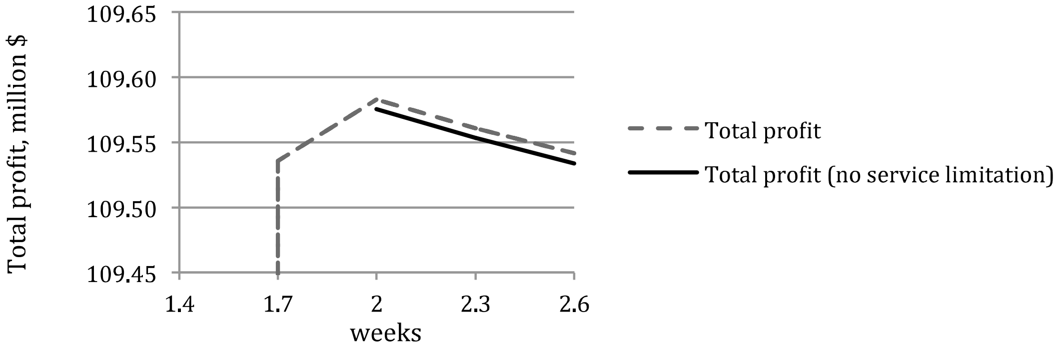


Figure 8.2: Total profit from container management as a function of container turn-around time in the inland region

Table 8.2: Inland service restriction with a change of average container turn-around time t_{IT}

Parameters	Average container turn-around time in inland, weeks				
	$t_{IT} = 1.4$	$t_{IT} = 1.7$	$t_{IT} = 2$	$t_{IT} = 2.3$	$t_{IT} = 2.6$
Rejected shipments in total demand (%)	12.2	0.8	0.8	1.0	1.1
– Import shipments (%)	5.0	0.8	0.8	1.0	1.1
– Export shipments (%)	7.2	0	0	0	0

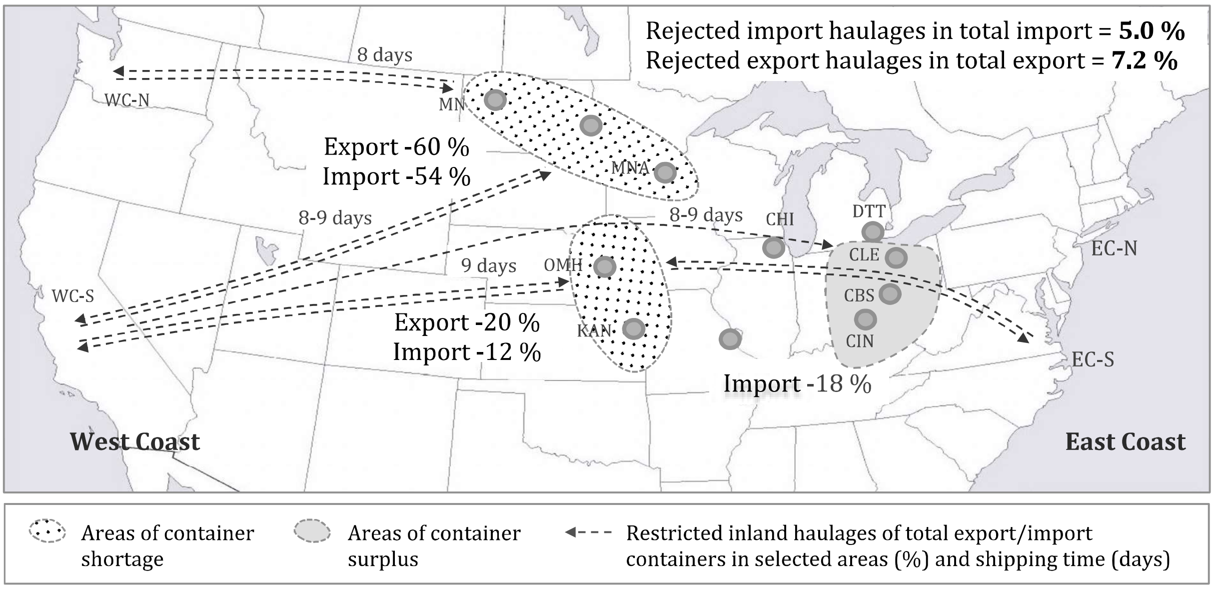


Figure 8.3: Inland service restriction with average container turn-around time limited to 1.4 weeks

The presented results correspond with the information about the inland haulage services provided by Maersk Line (Maersk Line, 2016). According to the ocean carrier's revised inland service map, the import and export shipments going through the West Coast gateway ports are no longer provided for the customers in the Eastern areas of the U.S. Midwest region, i.e.: North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, and Missouri. A similar inland service reduction is made for the import and export shipments going through the East Coast Ports. As a result, the model's behavior appears to be realistic while taking into account simplifications made in the modeling process.

8.3 Effect of inland turn-around time on maritime container management

Container turn-around time in the inland region (t_{IT}) affects the availability of empty equipment in the ports and thus directly influences the decisions on empty container management in the global shipping network. In order to see the change in the repositioning, the extended Maritime Model is run with different values of container travel time in different regions. The main assumptions for the input data are as follows:

- The total shipping cost for empty containers includes only fuel and handling charges.
- Container travel time in inland for the basis scenario equals 0. Containers are immediately available for the reuse after unloading of import shipments in the ports. The other cases assume that containers spend a certain time in the inland region being delivered to the customer locations, unloaded, reloaded, and returned back to ports.
- Container turn-around time is changed in all regions simultaneously, as well as in a separate region only.
- For simplicity reasons, it is assumed that the demand for shipping stays constant in all cases, regardless of container travel time in the region.

- Finally, in order to obtain a more distinct picture of changes, the total container inventory at carrier's disposal is set to a more limited value (Container-Traffic-to-Container-Fleet ratio is changed from 5 to 7).

The basic scenario with t_{IT} = 0: The main empty container flow in the basic scenario is focused on the Europe-Asia connection and the transpacific route due to the least expensive average repositioning cost. At the same time, the East Coast of North America is associated with the highest average shipping cost to Asia and thus has the least portion of empty container outflow.

It must also be noted that the storage capacity in all ports is limited. As a result, a certain portion of empty containers are forced to be shipped out of all surplus areas due to capacity constraints in the ports, and not because of the actual need for empty containers in Asia. This situation refers particularly to the ports on the East Coast of North America. Excessive containers are then located and stored in Shanghai, as it represents one of the cheapest repositioning destinations from other regions. Figure 8.5 demonstrates that the storage level in Shanghai is kept to the full, while the storage level in other ports reaches the level of empty container volumes that are exactly needed for import shipments.

Further on, container turn-around time in the inland region is increased. The results show that the change in empty container repositioning depends greatly on the region, where container travel time is being changed (Table 8.3).

Increase in the inland travel time (t_{IT}) in container surplus regions: A longer container turn-around time in container surplus regions like North America affects in the first place the accumulation of container surpluses in the ports. With a longer travel time (e.g. t_{IT} = 2 weeks), the number of empty containers stored idle in the ports is declining. As a result, fewer containers need to be repositioned out of the region due to the limitations of storage capacities. Table 8.3 demonstrates that the share of empty container repositioning drops down by 6% mainly because of reduced inflow of excessive empty equipment to Shanghai. Therefore, the increase in container turn-around time in the region with container surpluses does not necessarily lead to a negative effect on the total profit from container management. In this case, the reduced empty container repositioning has a positive effect on the total profit from container management (Figure 8.4).

A further increase in the inland travel time (e.g. t_{IT} = 4 weeks) reduces the total container surplus even more. However, in this case, more containers need to be repositioned from more expensive origin regions. For example, more empty containers are being shipped to HK/TOK from Europe rather than from West Cost of North America. As a result, even though the total share of empty container repositioning is decreased, a higher cost of shipping leads to a negative change in the profit from container management.

Increase in the inland travel time in container shortage regions: A longer inland time in container shortage areas like Asia increases in the first place the demand for empty containers, which, consequently, leads to a greater magnitude of repositioning. For instance, the scenario with the inland travel time of 4 weeks shows the increased empty container inflow to almost all Asian ports (Table 8.3). As a result, the total profit from container management declines significantly (Figure 8.4).

Increase in the inland travel time in all regions: Finally, the longer inland travel time of container in all regions affects both, the surplus and the demand for empty containers. As a result, fewer containers need to be repositioned to Asia due to the storage limitations in the ports. Container inflow to Shanghai can be reduced. However, more empty containers need to be shipped on other, more expensive, connections in order to cover an increased container shortage in the rest of the Asian ports (Table 8.3). The total profit from container management declines the most. Moreover, a further increase in the inland travel time results in an insufficient container inventory for the given shipping demand and thus makes the problem infeasible.

Table 8.3: Relative change in empty container in-/outflow in a port as a result of increased container travel time in different regions (%)

Region	t_{IT} (week)	Container outflow			Container inflow				ECR	Change in ECR
		EU	ECNA	WCNA	SIN	HK	SHG	TOK		
North America/Europe	2	-7	-6	-6	0	0	-44	0	16.18	-6
North America/Europe	4	-11	-13	-12	0	0	-40	0	15.39	-12
Asia	2	0	0	0	4	13	-13	4	17.11	0
Asia	4	3	0	0	8	26	-22	8	17.34	2
All regions	2	-4	-6	-6	4	13	-34	4	16.34	-5
All regions	4	Not enough containers								

ECR – share of empty container repositioning in total shipping (%)

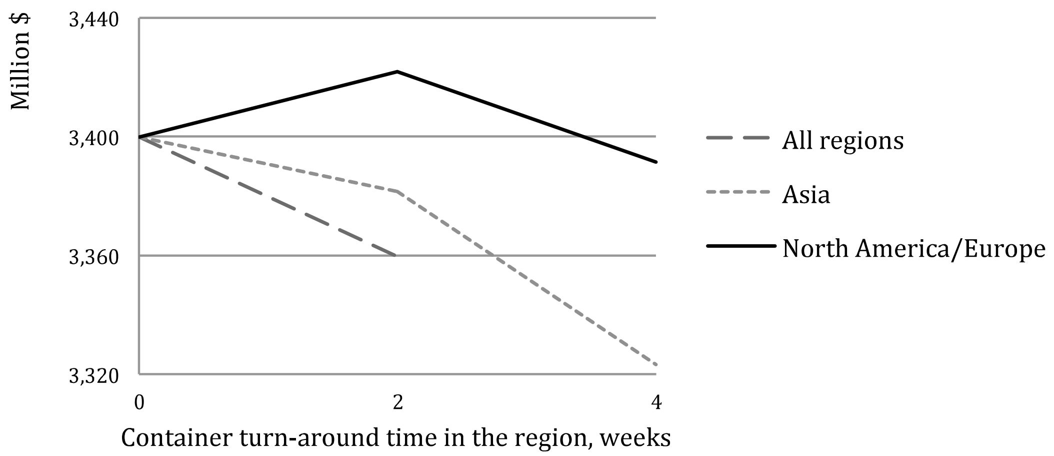
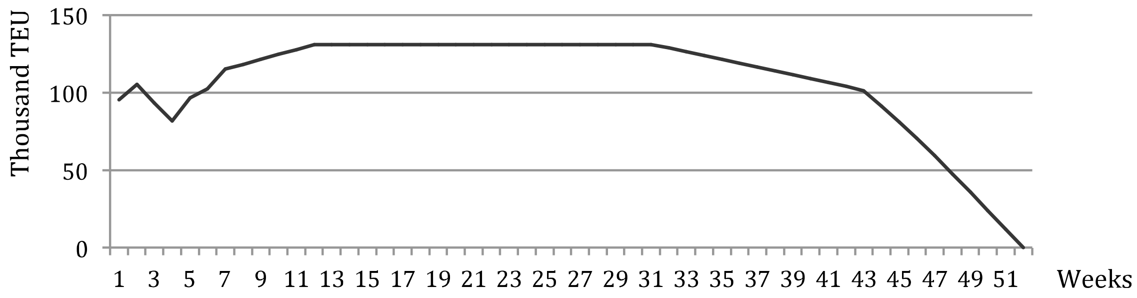
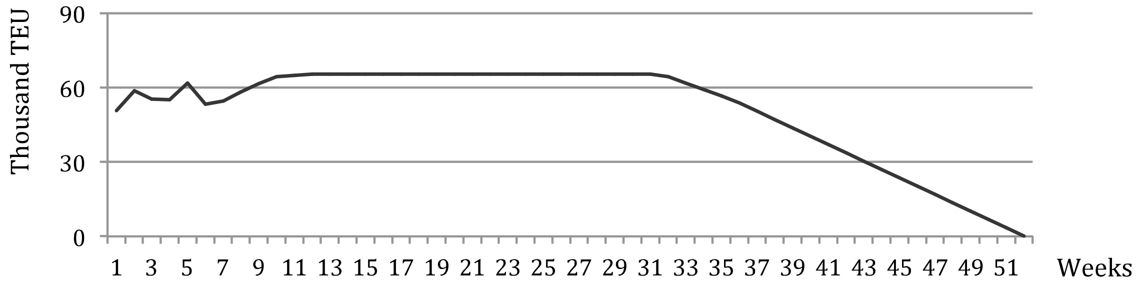


Figure 8.4: Total profit from global container management as a function of container turn-around time in the inland region

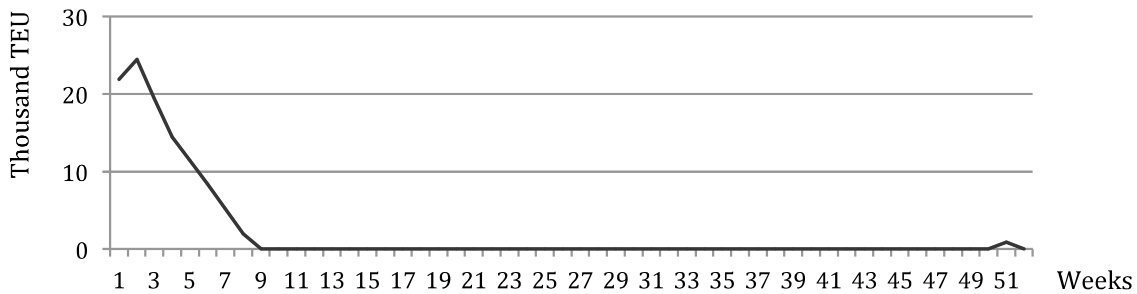
Thus, results show that the time of container turn-around in the inland region affects both, the magnitude of empty container flow and its distribution in the global shipping network. As a result, the incorporation of this parameter into container management models enables providing more accurate decisions on empty container repositioning.



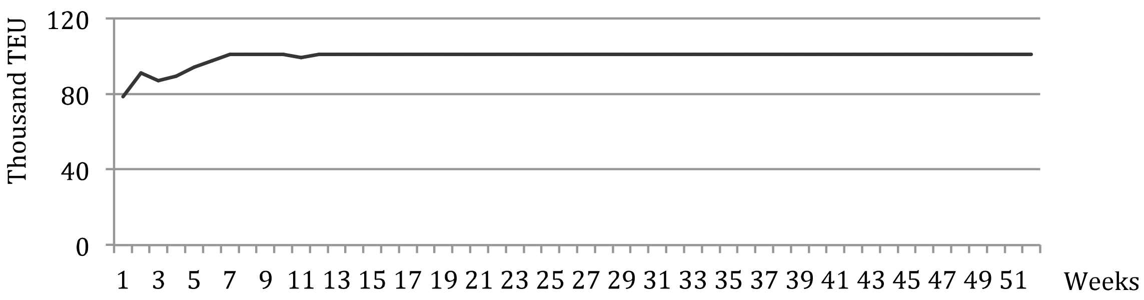
a) Singapore



b) Hong Kong



c) Tokyo



c) Shanghai

Figure 8.5: Containers stored in Asian ports over the planning horizon

8.4 Summary of results

Developed Maritime and Inland Models enable container management in their respective networks with a given data on an average container turn-around time in the inland region. The common data enable the coherence of results from both transport networks.

The Inland Model optimizes all inland container movements with a requirement to return all import containers back to the ports empty or loaded in a fixed interval of time. When a very tight constraint is put on the container travel time, the proposed model facilitates the decisions on which customers to serve while meeting a given time requirement and provides the profit from such inland service network. Additionally, the model specifies: 1) a change in the inland container flow as a result of inland haulage rejection; 2) a change in an average profit from the seaport connection with the region as a result of losing the customers on the whole shipping chain. The latter parameter can be then integrated with the results of the Maritime Model.

Results of the given case study for inland container management show that in the situation of limited container turn-around time in the U.S. Midwest region, the inland services are being restricted in the first place in Minnesota, North Dakota, and Nebraska. These are the hard-to-reach areas with container surplus. Moreover, mainly the export customers are being rejected in inland haulage since export shipments increase the total turn-around time of containers.

The Maritime Model optimizes global container management knowing when in a time containers become available for the reuse after inland trips. Incorporation of the inland travel time into the model enables to provide more accurate decisions on empty container repositioning since container turn-around in the inland region affects both, the magnitude and the distribution of empty container flow in the global shipping network.

Results of the given case study show that the changes in the global repositioning depend on the region, where the container travel time is changing. A longer container turn-around time in container surplus regions affects in the first place the accumulation of the surpluses in the ports while a longer inland time in container shortage areas increases the demand for empty boxes. As a result, the increase in container turn-around time in the region with container surpluses does not necessarily lead to a negative effect on the total profit from container management. In the situation when the storage capacity in the ports of North America/Europe is fairly tight, a slight increase in inland travel time reduces only the amount of containers stored in the ports. Consequently, the amount of repositioning due to the storage capacity limitation is reduced as well. This change has a positive effect on total profit from container management. In all other cases, a strong increase in container travel time in the inland regions normally leads to the higher repositioning costs.

9 Conclusions and recommendations

9.1 Conclusions

For liner shipping companies, empty container repositioning represents a highly relevant problem in both maritime and inland transport service networks. However, due to the complexity of the whole network, as well as its large dimension, the problem of empty container management has been typically treated for global and regional levels separately or with a focus solely on specific routes. A holistic view of the problem, which implies the existence of connecting links between the transport networks, needs to be more carefully considered. The literature review in Chapter 2 also reveals that the mathematical models for global container management have not been addressing the short-term leasing option with all its specific conditions and requirements. While, at the same time, the models for regional container management have not been reflecting certain features that have been growing in relevance particularly in the North American intermodal transport network. One of these features is the tendency to speed-up the container turn-around time in the hinterland by cutting down a number of inland locations served by an ocean carrier. In light of this, an ocean carrier can plan its regional container management considering the rejection of certain customer demands for ocean carrier's inland services.

Chapter 3 presents a specific approach to container management optimization in ocean carrier's transport networks. Tactical decision-making process related to container movements is represented as a decentralized system with the global and regional levels. The managerial levels interconnect through the certain control parameters, of which the main one is container turn-around time in the inland region. Inland container management is performed with a requirement to return all regional containers back to the ports no later than in a given time interval, while the maritime container flows are managed knowing that all containers arriving at a port will be available again (empty or reloaded) at a given time. In cases where the ports of the maritime shipping network belong to the same inland region and exchange the containers between themselves, an additional control parameter that accounts for redistribution of the regional container flow between the ports can be added. In this case, however, the fractional numbers prohibit an integer solution with the general solvers like CPLEX or Gurobi, and thus, the application of rounding techniques or algorithms must be considered.

Basing on the described approach, two tactical models for maritime and inland transport networks are proposed in Chapter 3. Both models include container turn-around time in the regions as the main parameter, which enables the connection between networks and the coherence between the models' results. At the same time, the Maritime Model focuses on the global container management with a more realistic representation of the short-term leasing. It also involves the option of demand rejection if the vessel capacity is not adequate for the total container transportation, or if the freight rate surcharges in the headhauls from Asia are not enough to cover the empty repositioning cost or other losses. The Inland Model optimizes empty regional container flows, considering the option of inland service restriction, which is specifically relevant in the North American hinterland. It implies the limitation of a number of inland locations served by an ocean carrier basing on the cost or time reasons. Empty movements include the street-turn containers, which are modeled using certain parameters. Finally, due to the rejection of requests for inland haulage, an ocean carrier can lose the customers on the whole shipping chain. As a result, the Inland Model incorporates an averaged profit from the shipments on both sea and land leg into its objective function.

Chapters 4 and 5 present the detailed explanation of the mathematical formulation of the Maritime and Inland Models, respectively. The basic formulation of the Maritime Model focuses on the short-term leasing option only. The problem is formulated as a dynamic multi-commodity network flow model that seeks to maximize the profit from the global container management. Later on, the model is extended further in order to incorporate the weighted-averaged container travel time in the region. The Inland Model also has a formulation of a dynamic network flow model that seeks to maximize the profit from the regional container management including also an average profit from the seaport connection with the inland region. One of the constraints in the model limits the weighted-averaged container turn-around time in the region so that two models can correspond to each other. The models are then implemented using AMPL and solved with Gurobi 6.5.0.

Chapter 6 explains the case study and the results of the Maritime Model. The global network focuses on three main trade routes: Transpacific, Transatlantic, and North Europe–Far East. The size of the physical network is, however, limited to 9 major ports in the trade region. In order to reduce the size of the time-space network, the ports on the East and West Coast of North America are presented as aggregated nodes. The aggregation techniques are explained. The total planning period equals 1 year, divided into 52 time periods (weeks). The 1456 transport demands are generated based on the weekly distribution of container traffic in the global network. Initial container inventory is distributed among ports according to their export volume.

In order to test the model with the short-term leasing option in various settings, Chapter 6 presents a set of scenarios, which include: different demand patterns, different financial, managerial and technical conditions. Computational results show that the small test instances for the Maritime Model can be solved in a reasonable time. The large instances, however, are much more time-consuming, and therefore, an application of heuristic algorithms is preferable. Analysis of the model's results shows that a portion of empty container repositioning in the given shipping network makes up around 18% of the total transportation. This outcome corresponds with the estimations of the real-world situation made by the shipping experts. The results also show that the short-term leasing is economically reasonable only in specific cases: i.e. in the situation of inadequate vessel capacity. The leasing option is not profitable even when the shipping cost of empty containers is very high. It can be considered only when more favorable leasing conditions can be negotiated with lessor, specifically: the drop-off charges are reduced. The utilization pattern of leased containers can vary depending on the negotiated leasing conditions. When no minimum lease duration is required, containers are being on-hired in Asia at the beginning of the planning period and almost immediately used for specific trips on all shipping routes. Since a large number of the one-way trip lease is prohibited by the lessors, containers are being assigned to the round trips with backhauls to the ports, associated with the most expensive repositioning cost or the highest repositioning flow. When the minimum lease duration is required, containers are forces to circle longer in the shipping network. Leased containers can also be stored before the assignment to the next shipments. In both cases, a number of the one-way trip lease is very limited.

Additionally, the conducted sensitivity analysis enables to demonstrate the relations in the model. It shows that, in most scenarios, financial parameters related to repositioning and storage have the greatest potential for optimization. At the same time, among all lease-related factors, the off-hire quota has the greatest influence on the leasing decisions. A high importance of the off-hire quota in the leasing conditions is also confirmed by the experts' opinion. Thus, the model can assist a carrier in negotiation with the leasing companies about the port-related off-hire portions and other conditions of container return. Finally, the results of the global container management show that the demand rejection in the situation of high empty container repositioning cost has a potential to maximize the total profit and thus can be incorporated into the tactical planning.

The case study for the regional container management in Chapter 7 focuses on the U.S. Midwest region. It presents the inland service network, which consists of 4 ports nodes, 12 main intermodal terminals (10 of which have the empty container depots), and 22 customer locations. Each customer location represents an aggregated cluster of import or export customers in the terminal service area with a radius of 200 miles. Demand for inland haulages is generated for the planning period of 181 days taking into account the ship arrival/departures in the ports and is distributed in the network according to the population density with consideration of the export/import imbalance rate. The region of the case study has areas with container surplus and shortage, which creates a need for empty container repositioning between depots. The inland rates of the haulage, as well as the transportation time and cost of all empty container movements in the network, are set based on the publicly available resources. Rail shipments of empty containers to the ports get a substantial discount.

The computational results later in Chapter 7 show that Gurobi 6.5.0 enables a good performance of the Inland Model even with relaxed parameters for integer variables. The computational time is, however, increased significantly for the test instances with larger planning horizons. Further on, the optimization potential of the proposed strategy is discussed. Results demonstrate that in the situation of the high repositioning cost, when the increase in the inland tariffs does not represent a solution, the limitation of inland haulages for certain customers is economically reasonable for an ocean carrier. Limitation of inland services for import shipments avoids the long-distance repositioning of empty container surpluses to the West Coast ports, while the restriction of inland services for export shipments avoids the unproductive inter-depot repositioning to the areas with container shortage. These decisions, however, directly depend on the transportation cost. Moreover, the increase of vessel capacity for repositioning to Asia from the East Coast ports can represent an alternative to the proposed strategy. The derived results correspond to the practice of certain ocean carriers that started to limit their inland services in the U.S. Midwest region. Thus, the proposed Inland Model can be used for the optimization of the regional container management with restricted container travel time, assisting the decisions on inland service restriction.

Finally, Chapter 8 presents the results of both models from a holistic perspective. Having provided input data about global transport demand and the weighted-average travel time that containers spend in the U.S. region, the Maritime Model determines the magnitude of empty container repositioning and presents the total profit from the corresponding global container management. At the same time, the Inland Model determines the profit from regional container management with a restricted weighted-average container turn-around time, and it presents an average change in the profit on the sea connection with a region in the case when not all customer orders can be satisfied. The latter parameter can also be integrated with the results of the Maritime Model. At the end of the chapter, the influence of inland travel time on the global and regional container management is discussed in more detail. The results show that a longer container turn-around time in the region does not necessarily lead to a greater volume of empty container repositioning in the global shipping network. In the regions with container surplus (e.g. North America, North Europe) a slightly longer container travel time reduces only the accumulation of equipment in the depots. Thus, in the situation of tight storage capacities, a portion of empty containers repositioned due to capacity reasons can be avoided. At the same time, the Inland Model identifies the customer areas that can be no longer provided with inland transport services due to a tighter restriction of container turn-around time in the region.

9.2 Recommendations

The proposed models demonstrate the application of existing methods of linear and integer programming with the purpose of 1) studying the deployment of owned and leased containers in different settings, and 2) identifying the possible potentials for optimization. For the better practical solutions certain improvements can be recommended for both models:

Maritime Model

- Introduction of a longer planning period with a purpose of a better comparison of the short- and long-term leasing as well as the purchasing option;
- Application of more robust algorithms for the network aggregation and the disaggregation of the results;
- Application of heuristic algorithms for the improvement of integer solutions of the models as well as their computation time, etc.

Inland Model

- Testing of the model on the inland regions with a larger scale and multiple port areas;

- Extension of the model with an option of closing the empty container depots in the inland locations, where the carrier's haulage is no longer offered. In this case, an additional variable for depot selection needs to be introduced to enable such decisions;
- Introduction of an additional option of restricting the carrier's haulages till certain intermodal terminals located in the proximity of a customer cluster. In this case, the movement of a maritime container can stop both in a port and in a major inland facility.

The proposed models can also be applied in other business areas. For example, the proposed model for the global container management can be applied not only to the ocean carriers but the leasing companies as well. With the slight modifications in the objective function, the model can assist the leasing companies in setting their policies for container pick-up and drop-off while taking into account the possible container repositioning. The objective function of the profit obtained from container management will represent the difference between the price of leasing and all associated costs for the leasing company: e.g. cost of empty container movements, repair, etc.

Finally, it must be noted that the model for inland container management needs to be adopted into the real shipping company's operation in order to see the actual potential effects of the proposed strategy.

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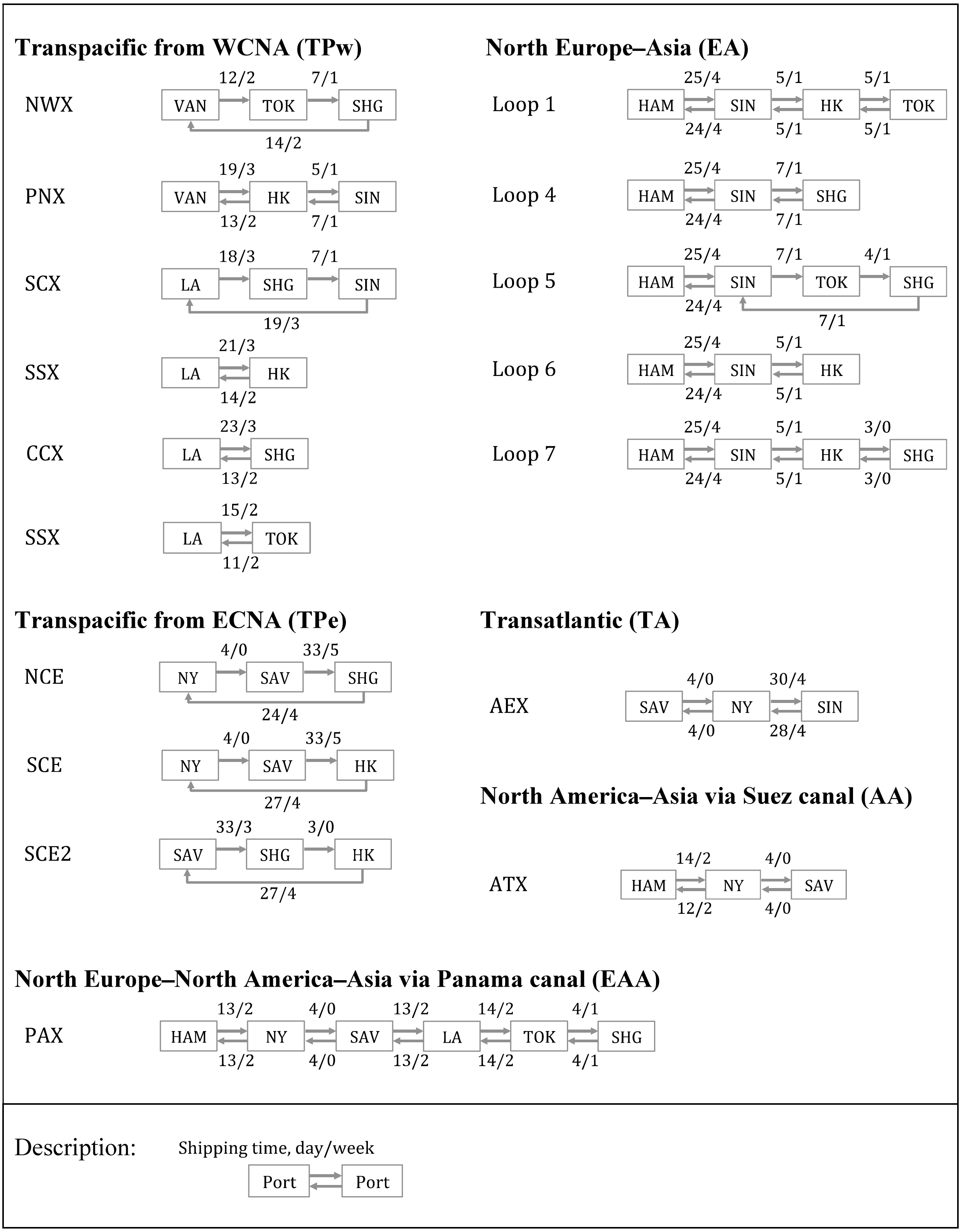
Appendix A: Input data for the Maritime Model

Table A.1: Liner services on the main trade routes (Hapag-Lloyd, 2012)



Estimation of weekly transport demand between pair of ports in the shipping network of the case study

Table A.2: Annual container traffic on the main trade routes (TEU) and imbalance rates in 2010

Route	Outbound	Inbound	Imbalance
North America–Far East Asia (NA-AS)	8577000	13497000	0.64
North America–North Europe (NA-EU)	1683000	2321000	0.73
North Europe–Far East Asia (EU-AS)	4596000	8811000	0.52

Source: Containerisation International (2011a)

Table A.3: Transshipment volume in selected ports in 2010 (TEU)

Region	Port	Transshipment volume	Total in the region
Europe	Hamburg	7900000	7900000
North America	New York	5292020	18463410
	Savannah	2825179	
	Los Angeles	7831902	
	Vancouver	2514309	
Asia	Singapore	28430800	85318015
	Shanghai	29069000	
	Hong Kong	23532000	
	Tokyo	4286215	

Source: Containerisation International (2011b)

Table A.4: Weekly container traffic on the trade route, statistics and results from own estimation

STATISTICS*							
Route	Outbound (TEU)	Inbound (TEU)	Total (TEU)	$Share_{Out}$	$Share_{In}$	$Share_T$	Imbalance rate
NA-AS	164942	259558	424500	0.6	0.5	0.6	0.64
NA-EU	32365	44635	77000	0.1	0.1	0.1	0.73
EU-AS	88385	169442	257827	0.3	0.4	0.3	0.52
Total flow	285692	473635	759327	1	1	1	
OWN ESTIMATIONS							
Route	Outbound (TEU)	Inbound (TEU)	Total (TEU)	$Share_{Out}$	$Share_{In}$	$Share_T$	Imbalance rate
NA-AS	37541	59075	96616	0.6	0.6	0.6	0.64
NA-EU	7704	10625	18329	0.1	0.1	0.1	0.73
EU-AS	17735	33528	51263	0.3	0.3	0.3	0.53
Total flow	62980	103228	166208	1	1	1	

Note: $Share_{out}$ – share of outbound traffic of a trade route in total outbound flow in the transport network.
$Share_{in}$ – share of inbound traffic of a trade route in total inbound flow in the transport network.
$Share_T$ – share of traffic on a route.

* Annual container traffic is dived by 52 weeks.

Table A.5: Resulted distribution of the weekly transport demand in the unaggregated shipping network (%)

Ports	HAM	NY	SAV	LA	VAN	TOK	SIN	SHG	HK	Export	Import
HAM	–	4.2	0.9	1.3	–	03	5.0	2.8	2.5	17	25
NY	3.1	–	–	–	–	0.1	1.3	1.6	1.2	7	11
SAV	0.7	–	–	–	–	0.0	0.7	1.9	1.4	5	7
LA	0.9	–	–	–	–	1.7	1.4	3.8	1.6	10	15
VAN	–	–	–	–	–	0.4	1.6	2.5	1.3	6	9
TOK	0.3	0.8	0.5	3.8	0.0	–	–	–	–	5	3
SIN	9.6	2.0	1.1	4.6	4.6	–	–	–	–	22	10
SHG	5.5	1.8	2.5	2.6	4.6	–	–	–	–	17	13
HK	4.8	1.8	2.2	2.6	–	–	–	–	–	11	8

Shipping time, cost, and capacity of arcs in the shipping networks of case study

Table A.6: Shipping time, cost, and capacity in the aggregated sub-network of each liner service

Arc	Service	Time (weeks)	Cost ($/TEU)	Capacity (TEU)
EU-SIN	EA	4	660	24066
SIN-SHG	EA	1	185	4813
SIN-HK	EA	1	132	14440
HK-SHG	EA	0	79	4813
HK-TOK	EA	1	132	4813
TOK-SHG	EA	1	106	4813
SHG-SIN	EA	1	185	9626
SIN-EU	EA	4	634	24066
SIN-TOK	EA	1	185	4813
SHG-HK	EA	0	79	4813
HK-SIN	EA	1	132	14440
TOK-HK	EA	1	132	4813
ECNA-SHG	TPe	5	908	6618
SHG-ECNA	TPe	4	661	3309
ECNA-HK	TPe	5	908	3309
HK-ECNA	TPe	4	743	6618
SHG-HK	TPe	0	83	3309
WCNA-SHG	TPw	3	488	8423
SHG-SIN	TPw	1	190	5415
SIN-WCNA	TPw	3	515	5415
WCNA-TOK	TPw	2	352	8423
TOK-SHG	TPw	1	108	5415
SHG-WCNA	TPw	2	352	8423
WCNA-HK	TPw	3	515	8423
HK-SIN	TPw	1	136	5415
SIN-HK	TPw	1	136	5415
HK-WCNA	TPw	2	352	8423
TOK-WCNA	TPw	2	352	3008
EU-ECNA	TA	2	398	4512
ECNA-EU	TA	2	398	4512
EU-ECNA	EAA	2	417	3008
ECNA-WCNA	EAA	2	417	3008
WCNA-TOK	EAA	2	417	3008
TOK-SHG	EAA	1	128	3008
SHG-TOK	EAA	1	128	3008
TOK-WCNA	EAA	2	417	3008
WCNA-ECNA	EAA	2	417	3008
ECNA-EU	EAA	2	417	3008
ECNA SIN	AA	4	962	3610
SIN-ECNA	AA	4	898	3610

Table A.7: Shipping time, cost, and capacity in the aggregated network with accumulated liner services

Arc	Time (week)	Cost ($/TEU)	Capacity (TEU)
EU-SIN	4	660	24066
SIN-SHG	1	185	4813
SIN-HK	1	132	19855
HK-SHG	0	79	4813
HK-TOK	1	132	4813
TOK-SHG	1	106	13236
SHG-SIN	1	185	15041
SIN-EU	4	634	24066
SIN-TOK	1	185	4813
SHG-HK	0	79	8122
HK-SIN	1	132	19855
TOK-HK	1	132	4813
ECNA-SHG	5	908	6618
SHG-ECNA	4	661	3309
ECNA-HK	5	908	3309
HK-ECNA	4	743	6618
WCNA-SHG	3	488	8423
SIN-WCNA	3	515	5415
WCNA-TOK	2	350	11431
SHG-WCNA	2	352	8423
WCNA-HK	3	515	8423
HK-WCNA	2	352	8423
TOK-WCNA	2	360	6017
WCNA-ECNA	2	417	3008
EU-ECNA	2	403	7521
ECNA-WCNA	2	417	3008
SHG-TOK	1	128	3008
ECNA-EU	2	417	7521
ECNA-SIN	4	962	3610
SIN-ECNA	4	898	3610
TOK-WCNA	4	660	24066

Appendix B: Selected results of the Inland Model

Table B.1: Comparison of selected resulting parameters in the basic scenario with and without inland service restriction

Basic scenario	W/o service limitation	With service limitation	Absolut change	Relative change (%)
FINANCIAL PARAMETERS ($ million)				
Total profit from inland service network incl. an average profit from sea port connection	110	110	0.01	0.01
Average profit from sea port connection with the region	71	70	**-0.84**	-1.2
– Profit from shipments on sea legs	89	87	-1.57	-1.8
– Cost of maritime repositioning on sea legs	18	17	-0.73	-4.0
Profit from inland container management	39	40	**0.85**	2.2
Profit from shipments on inland legs	110.4	109.7	-0.7	-0.6
Cost of inland empty container movements	71	70	**-1.5**	-2.2
– Empty drayage to/from customers	53	52	-0.4	-0.8
– Street-turn	0.98	0.97	0.0	-1.7
– Inter-depot repositioning	0.79	0.79	0	0
– Empty repositioning back to ports	17	16	**-1.1**	-6.6
Storage cost	0.34	0.34	0.0	-1.1
– Storage in depots	0.31	0.31	0.0	-1.2
– Storage in ports	0.03	0.03	0.0	-0.4
NON-FINANCIAL PARAMETERS (%)				
Rejected demand in total inland shipments	0	0.8	–	–
– Import demand in total import	0	1.4	–	–
– Export demand in total export	0	0	–	–
Change in maritime repositioning due to demand rejection (%)	0	-4.2	–	–

Table B.2: Absolut change in selected resulting parameters with a change of an average container turn-around time in the inland region (t_{IT})

Scenarios	W/o service restriction			With service restriction				
	$t_{IT} = 2$	$t_{IT} = 2.3$	$t_{IT} = 2.6$	$t_{IT} = 1.4$	$t_{IT} = 1.7$	$t_{IT} = 2$	$t_{IT} = 2.3$	$t_{IT} = 2.6$
CHANGE IN FINANCIAL PARAMETERS ($ million)								
Total profit from inland service network incl. an average profit from sea port connection	Base	**-0.02**	**-0.04**	-35	0	0.01	**-0.01**	**-0.03**
Average profit from sea port connection with the region	Base	0	0	-6	-1	-0.84	-1.00	-1.12
– Profit from shipments on sea legs	Base	0	0	-3	-2	-1.57	-1.87	-2.09
– Cost of maritime repositioning	Base	0	0	2	-1	-0.73	-0.87	-0.97
Profit from inland container management	Base	**-0.02**	**-0.04**	-30	1	0.85	**0.99**	**1.08**
Profit from shipments on inland legs	Base	0	0	-15	-1	-0.69	-0.83	-0.92
Cost of inland empty container movements	Base	0	0	-5	-2	-1.53	-1.83	-2.04
– Empty drayage to/from customers	Base	0	0	-6	0	-0.42	-0.51	-0.57
– Street-turn	Base	0	0	0	0	-0.02	-0.02	-0.02
– Inter-depot repositioning	Base	0	0	-1	0	0	0	0
– Empty repositioning back to ports	Base	0	0	2	-1	-1.09	-1.31	-1.46
Storage cost	Base	**0.02**	**0.04**	0	0	0	**0.017**	**0.037**
– Storage in depots	Base	0.03	0.06	0	0	0	0.02	0.05
– Storage in ports	Base	-0.01	-0.02	0	0	0	-0.01	-0.02
NON-FINANCIAL PARAMETERS (%)								
Rejected demand in total inland shipments	0	0	0	12.2	0.8	0.8	1.0	1.1
– Import demand	0	0	0	5.0	0.8	0.8	1.0	1.1
– Export demand	0	0	0	7.2	0	0	0	0
Change in maritime repositioning due to demand rejection (%)	0	0	0	11.4	-4.2	-4.2	-5.0	-5.5

Appendix C: Input data for the Inland Model

Estimation of drayage distances in the case study

Assumptions:

- Terminal service area is approximated to a circle with radius *R* and a terminal located in the center
- Customer locations are uniformly distributed within the circle zone

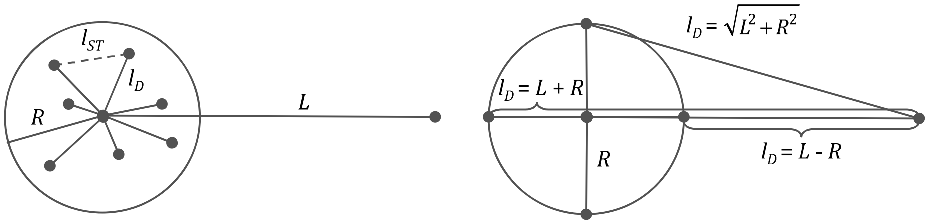


Figure C.1: Terminal service area and the trucking distances to/from the customer points

Calculation of average drayage distance within terminal/depot service area l_D:

- Number of customers located on distance *R* from the terminal equals circumference of the circle: $2\pi R$
- Total distance traveled to such customers: $2\pi R^2$
- Total distance traveled from the center to any location within the circle: $\int_0^R 2\pi R^2 = \frac{2}{3}\pi R^3$
- Total maximum number of customer locations within the area equals the volume of the circle: πR^2
- Average distance from terminal to any location within the area: $l_D = \frac{\frac{2}{3}\pi R^3}{\pi R^2} = \frac{2}{3}R$

In order to account for the actual non-linear road conditions, the estimated distance function is corrected with a circuity factor *CF*=1.2 (O'Sullivan and Morrall, 1996) $l_D = \frac{2}{3}R \cdot CF$

Average distance between any two points evenly distributed in a circle with radius *R* equals $\frac{128}{45\pi}R \approx 0.91R$ (Burgstaller and Pillichshammer, 2009).

Then, the street-turn distance between import and export customers within depot service including circuity factor results in $l_{ST} = 1.092R$

Finally, the average drayage distance between a customer within a circle area and another depot, located on distance *L* from the center of the area, is calculated as an average distance for 4 extreme points on the circle:

$$\frac{2\sqrt{L^2+R^2}+(L+R)+(L-R)}{4} = \frac{1}{2}\left(L+\sqrt{L^2+R^2}\right)$$

Estimation of import and export container flow in the U.S. Midwest region

Table C.1: Import inflow into the U.S. Midwest region per vessel call at a specific port gateway estimated for the year 2011

Trade line	Asia–North America				Europe–N. America		
Port gateway	WC-S	WC-N	EC-N	EC-S	EC-N	EC-N	Sum
Typical vessel capacity on a trade route[11] (TEU)	6300	6300	4700	4700	4700	4700	–
Portion of containers on a vessel, destined for a port gateway[12]	1	0.75	0.5	0.5	0.5	0.5	–
Portion of containers destined to the Midwest[13]	0.2	0.2	0.2	0.2	0.2	0.2	–
Transloading portion[14]	0.7	0.7	0.7	0.7	0.7	0.7	–
Resulted import flow (TEU)	882	662	329	329	329	329	2860
Import distribution between ports	0.31	0.23	0.12	0.12	0.12	0.12	1.00

Table C.2: Population distribution in the selected metropolitan statistical areas in the U.S. Midwest region in 2011 (U.S. Census Bureau, 2015)

Metropolitan statistical area	Population	Share (%)
Cincinnati-Middletown, OH-KY-IN	2130151	0.07
Columbus, OH	1836536	0.06
Cleveland-Elyria-Mentor, OH	2077240	0.07
Detroit-Warren-Livonia, MI	4296250	0.15
Chicago-Joliet-Naperville, IL-IN-WI	9461105	0.33
St. Louis, MO-IL	2812896	0.10
Kansas City, MO-KS	2035334	0.07
Minneapolis-St. Paul-Bloomington, MN-WI	3279833	0.11
Minot	69540	0.00
Fargo	208777	0.01
Omaha-Council Bluffs, NE-IA	865350	0.03
Total	29073012	1.00

[11] Vessel capacity is taken as rounded nominal vessel capacity in a vessel cluster. Typical vessel capacity on a route is estimated for the year 2011 based on several studies (Drewry Maritime Research, 2014; Alphaliner, 2012; Devidson, 2014; Dekker, 2014).

[12] Own estimation based on the review of liner shipping services.

[13] Portion of import flow destined to the U.S. Midwest region is defined based on the population density. Based on the statistical data on the U.S. population density in 2011 (U.S. Census Bureau, 2015), around 22% of population is focused in the Midwest region.

[14] Based on Wilson and Benson, (2009).

Table C.3: Resulted distribution of the import container flow between the customer locations (TEU)

Trade route	Asia–North America				Europe–North America		Total import (TEU)
Port node / Inland point	WC-N	WC-S	EC-N	EC-S	EC-N	EC-S	
Cincinnati	45	34	17	17	17	17	34
Columbus	39	29	15	15	15	15	30
Cleveland	44	33	16	16	16	16	32
Detroit	91	68	34	34	34	34	68
Chicago	201	151	75	75	75	75	150
St. Louis	–	45	22	22	22	22	44
Kansas City	43	32	16	16	16	16	32
Minneapolis	70	52	–	–	–	–	0
Minot	1	1	–	–	–	–	0
Fargo	4	3	–	–	–	–	0
Omaha	18	14	7	7	7	7	14

Table C.4: Resulted distribution of the export container flow the between customer locations (TEU)

Trade route	Asia–North America				Europe–North America		Total export (TEU)
Port node / Inland point	WC-N	WC-S	EC-N	EC-S	EC-N	EC-S	
Cincinnati	21	16	8	8	14	14	81
Columbus	18	14	7	7	12	12	70
Cleveland	21	16	8	8	13	13	79
Detroit	43	32	16	16	28	28	163
Chicago	94	71	35	35	62	62	359
St. Louis	–	21	10	10	18	18	77
Kansas City	48	35	18	18	18	18	155
Minneapolis	77	57	–	–	–	–	134
Minot	2	1	–	–	–	–	3
Fargo	5	3	–	–	–	–	8
Omaha	20	15	8	8	8	8	67

Characteristics of import and export shipments on sea and inland legs

Table C.5: Calculation of an average profit from import/export shipments on a trade route for the year 2011

	Parameters	Data for each trade route		Source/Calculation
		Asia–North America	Europe–North America	
1	Average vessel size (TEU)	6500	4500	Drewry Maritime Research (2014)
2	Vessel utilization rate	0.9	0,9	Alphaliner (2012)
3	Imbalance rate in 2011	0.47	0,82	Rodrigue et al. (2011)
4	Containers on a vessel on the headhaul to America (TEU)	5850	4050	(1) × (2)
5	Containers on a vessel on the backhaul from America (TEU)	2925	3321	(1) × (2) × (3)
6	Freight rates on the headhaul to America ($/TEU)	2506	2296	Drewry Research (2011)
7	Freight rates on the backhaul from America ($/TEU)	1317	1255	Drewry Research (2011). Rates on Asia–North America route is taken as an average between the rates for the West and East Coasts
8	Time of round voyage (days)	61	43	Based on review of liner services
9	Slot cost ($/TEU/day)	37	42	The relation between cost for 6500 TEU and 4500 TEU vessels is estimated as 0.9 based on cost comparison in the literature. NCDT (2012)
10	Revenue from headhauls ($)	14660100	9298800	(4) × (6)
11	Revenue from backhauls ($)	3852225	4167855	(5) × (7)
12	Cost of headhauls ($)	7244055	4063500	(8) × (9) / 2
13	Cost of backhauls ($)	7244055	4063500	(4) × (6) / 2
14	Profit from headhauls ($/TEU)	1141	1163	[(10) – (12)] / (1)
15	Profit from backhauls ($/TEU)	-522	23	[(11) – (13)] / (1)

Table C.6: Inland tariffs for the carrier's haulage on the inland leg "port – inland location" ($/TEU)

	Import shipment				Export shipment			
Port node / Inland point	WC-N	WC-S	EC-N	EC-S	WC-N	WC-S	EC-N	EC-S
Cincinnati	3296	3091	1491	1366	3127	3048	1410	1339
Columbus	3127	2993	1609	1394	2637	2611	1553	1544
Cleveland	3127	3030	1496	1473	2591	2735	1444	1593
Detroit	3918	3984	1589	1537	2993	2911	1493	1563
Chicago	2585	2467	1598	1622	2220	2151	1598	1481
St. Louis	2843	3011	1894	1870	2518	2503	1783	1762
Kansas City	2676	2764	2099	2231	2575	2391	1970	2090
Minneapolis	2929	3632	2553	2644	2585	3208	3022	3047
Minot	4371	5074	3995	4086	4027	4649	4463	4488
Fargo	3268	3971	2892	2983	2925	3547	3361	3386
Omaha	2920	2943	2269	2400	2604	2623	2527	2259

Table C.7: Total cost of an inland shipment for an ocean carrier ($/TEU)

	Import shipment				Export shipment			
Port node / Inland point	WC-N	WC-S	EC-N	EC-S	WC-N	WC-S	EC-N	EC-S
Cincinnati	2457	2290	987	885	2320	2255	921	863
Columbus	2320	2210	1083	908	1921	1899	1037	1030
Cleveland	2320	2240	991	973	1883	2000	948	1070
Detroit	2964	3018	1067	1024	2210	2143	989	1045
Chicago	1878	1782	1074	1094	1581	1525	1074	979
St. Louis	2088	2225	1315	1296	1824	1812	1225	1207
Kansas City	1953	2024	1483	1589	1870	1720	1377	1474
Minneapolis	2158	2731	1852	1926	1878	2385	2234	2254
Minot	2849	3422	2542	2616	2569	3076	2924	2944
Fargo	2321	2894	2014	2089	2041	2548	2396	2417
Omaha	2094	2113	1564	1671	1836	1852	1774	1556

Table C.8: Transit time for the carrier's haulage on the inland leg (days)

Inland point \ Port node	WC-N	WC-S	EC-N	EC-S
Cincinnati	3	4	9	8
Columbus	3	4	9	8
Cleveland	3	4	9	8
Detroit	3	4	8	7
Chicago	3	4	7	7
St. Louis	4	5	8	8
Kansas City	5	6	8	7
Minneapolis	5	7	7	8
Minot	6	8	8	9
Fargo	6	8	8	9
Omaha	6	7	9	8

Characteristics of inland transportation

Table C.9: Transportation cost and time between nodes (i,j) [15] of the inland service network

Node *i*		Node *j*		Parameter	
Inland point	Name	Inland point	Name	Cost ($)	Time (days)
Depot	Chicago-East	Depot	Chicago-West	250	0
Depot	Minneapolis	Depot	Chicago-West	258	2
Depot	Omaha	Depot	Chicago-West	589	1
Depot	Kansas City	Depot	Chicago-West	571	2
Depot	Kansas City	Depot	Detroit	673	4
Depot	Kansas City	Depot	Cleveland	729	4
Depot	Kansas City	Depot	Cincinnati	720	4
Depot	Chicago-East	Depot	Cincinnati	381	3
Depot	Columbus	Depot	Chicago-East	369	3
Depot	Cleveland	Depot	Chicago-East	405	3
Depot	Chicago-East	Depot	Detroit	345	3
Depot	St. Louis	Depot	Detroit	533	5
Depot	St. Louis	Depot	Cleveland	570	4
Depot	Cincinnati	Export location	Cincinnati	325	0
Depot	Cleveland	Export location	Cleveland	325	0
Depot	Chicago-West	Export location	Chicago	325	0
Depot	Chicago-East	Export location	Chicago	325	0
Depot	St. Louis	Export location	St. Louis	325	0
Depot	Kansas City	Export location	Kansas City	325	0
Depot	Minneapolis	Export location	Minneapolis	325	0
Depot	Omaha	Export location	Omaha	325	0

[15] For space reasons, links between depots are presented only for one direction. Return direction is accosted with the same cost and time.

Node *i*		Node *j*		Parameter	
Inland point	Name	Inland point	Name	Cost ($)	Time (days)
Depot	Minneapolis	Export location	Minot	1016	1
Depot	Minneapolis	Export location	Fargo	488	0
Import location	Cincinnati	Depot	Cincinnati	325	0
Import location	Columbus	Depot	Columbus	325	0
Import location	Cleveland	Depot	Cleveland	325	0
Import location	Detroit	Depot	Detroit	325	0
Import location	Chicago	Depot	Chicago-West	325	0
Import location	Chicago	Depot	Cincinnati	325	0
Import location	St. Louis	Depot	St. Louis	325	0
Import location	Kansas City	Depot	Kansas City	325	0
Import location	Minneapolis	Depot	Minneapolis	325	0
Import location	Omaha	Depot	Omaha	325	0
Import location	Minot	Depot	Minneapolis	1016	1
Import location	Fargo	Depot	Minneapolis	488	0
Depot	Cincinnati	Port	EW-N	298	3
Depot	Cincinnati	Port	EW-S	269	4
Depot	Cincinnati	Port	WC-S	965	8
Depot	Cincinnati	Port	WC-N	997	9
Depot	Columbus	Port	EW-N	356	3
Depot	Columbus	Port	EW-S	353	4
Depot	Columbus	Port	WC-S	787	8
Depot	Columbus	Port	WC-N	798	9
Depot	Cleveland	Port	EW-N	312	3
Depot	Cleveland	Port	EW-S	372	4
Depot	Cleveland	Port	WC-S	838	8
Depot	Cleveland	Port	WC-N	779	9
Depot	Detroit	Port	EW-N	332	3
Depot	Detroit	Port	EW-S	360	4
Depot	Detroit	Port	WC-S	909	7
Depot	Detroit	Port	WC-N	943	8
Depot	Chicago-East	Port	EW-N	374	3
Depot	Chicago-East	Port	EW-S	327	4
Depot	Chicago-East	Port	WC-S	600	7
Depot	Chicago-East	Port	WC-N	628	7
Depot	Chicago-West	Port	EW-N	374	4
Depot	Chicago-West	Port	EW-S	327	5
Depot	Chicago-West	Port	WC-S	600	8
Depot	Chicago-West	Port	WC-N	628	5
Depot	St. Louis	Port	EW-N	450	4
Depot	St. Louis	Port	EW-S	441	5
Depot	St. Louis	Port	WC-S	743	8
Depot	Kansas City	Port	EW-N	526	5
Depot	Kansas City	Port	EW-S	575	6
Depot	Kansas City	Port	WC-S	698	7
Depot	Kansas City	Port	WC-N	698	8
Depot	Omaha	Port	WC-N	715	9
Depot	Minneapolis	Port	WC-S	1030	8
Depot	Minneapolis	Port	WC-N	777	7

Table C.10: Storage capacity in ports and inland depots (TEU)

Port/Depot	Storage capacity
Cincinnati	634
Columbus	550
Cleveland	608
Detroit	1270
Chicago[16]	2810
St. Louis	712
Kansas City	598
Minneapolis	599
Omaha	261
EC-N	484
EC-S	484
WC-S	1448
WC-N	416

Table C.11: Capacity for empty container repositioning from a port gateway, presented for a weekly time horizon[17] (TEU)

Trade line	Asia–North America				Europe–North America	
Day of week \ Port	EC-N	EC-S	WC-S	WC-N	EC-N	EC-S
1	0	0	181	0	0	0
2	0	0	181	0	0	0
3	0	0	0	0	0	0
4	92	0	0	0	29	0
5	92	92	181	0	29	29
6	0	92	0	208	0	29
7	0	0	181	0	0	0

[16] Depots in Chicago-West and Chicago-East represent a single system with single storage capacity, shown in the table.

[17] The pattern is repeated for the rest of the planning horizon in the model (181 days).