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Intermodal Hinterland Transport Networks: from Information to Efficiency

HOW CAN INFORMATION SYSTEMS FOR INTERMODAL HINTERLAND TRANSPORT NETWORKS BE IMPROVED TO MAKE THE SUPPLY CHAIN MORE PREDITCTABLE?

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Table of Contents

Management summary

This report is of an advisory nature, describing a research on information system improvements for logistic environments, within the scope of a Bachelor thesis in Industrial Engineering and Management. The research is executed for Yellowstar Solutions BV, a company providing software solutions for supply chains with the goal to increase supply chain predictability through efficient communication between supply chain actors. The focus customer groups of this research, for which Yellowstar wants to improve their products, are intermodal hinterland transport networks. According to literature on operations research, throughput times of entities at terminals form the bottlenecks of such networks. For this purpose, research is done at an intermodal hinterland terminal operator, the terminal "CTS" of the Yellowstar customer 'Neska Schiffahrts-und Speditionskontor GmbH', to answer the following research question:

How can the communication within the intermodal hinterland transport network be improved by an Information System to minimize the average throughput time of entities at intermodal hinterland terminals?

The structure of this research is based on the Grounded Theory approach (Saunders, Lewis, & Thornhill, 2009), where the qualitative and quantitative data of the case study, of a terminal, is used to develop a theory, which is then tested within a simulation model to assess the validity and the usefulness as a solution for the research question.

The observations at the terminal pointed to the core problem, that forecasts for barge arrivals are based on too few parameters, leading to unreliable forecasts and related ineffective scheduling of crane operators. In detail, barge throughput times at terminals seem to be mainly based on the planned number of containers to be loaded and unloaded at a terminal. In reality, throughput times are also based on the number of containers loaded and unloaded from or to trains and trucks, since they are processed in parallel by the cranes, additional to the barges. These observations led to the following hypotheses to be tested as solutions for the research question:

1) Including a prediction of all crane operations at terminals in ETA calculations of barges decreases the forecast error for barge arrival times significantly.
2) A decreased forecast error for barge arrival times has a significant effect on a decrease in throughput times of transport vehicles and containers at a terminal.

To test these hypotheses, an intermodal hinterland transport network is simulated, with the software 'Siemens Tecnomatix Plant Simulation 11', and different forecast methods are tested within this simulation. The first forecast method includes only barge related containers, the second one also trains and trucks, the third one only barges and trucks.

In result, only the third forecast method, excluding train containers, led to a slight decrease of the barge arrivals forecast error, and to a reduced average total system throughput time of barges. The observed forecast errors (MSE about 16.000 – 45000 seconds) were still too large for a reliable prediction of ETAs, but the forecast method performed better (MSE decrease of about 27%), compared to the other two, the later a terminal is positioned within a network. Analysis indicated that a slight overforecasting, that barges arrive earlier than predicted, led to a better match of barge arrival times and planned crane operator shifts, resulting in a larger number of available cranes during barge arrivals and a decrease in terminal throughput times of barges by 12%.

In summary, the final advice is to connect the information systems of terminals within a hinterland transport network, to enable them to calculate arrival forecasts of barges independent from barge operator calculations. The information shared for forecast calculations should include the expected workloads at terminals a barge still must pass on their route, combined with most actual positioning data of barges from the i&Land application. In the future, improved interterminal communication should not be limited to the Neska network only, but could be expanded to other networks that are connected to single terminals of Neska. A requirement for a benefit from this exchange of information is further research to improve of the terminal workload forecast method, to decrease the barge arrivals forecast errors to a minimum.

With a minimum forecast error, more operational planning steps than only the crane planning could be improved. As an example, truck disposition planning could be shifted more to a same-day planning, with the chance to increase the amount of crossdocking activities, and therefore a further reduction of entity throughput times at terminals. Further research is advised to evaluate these options.

List of acronyms

Acronym	Meaning
B&R	Barge & Rail operations department
BMS	Barge Management System
CMS	Container Management System
CS	Customer Service department
CTA	Current Time of Arrival
CTS	Container-Terminal Cologne
DB	Deutsche Bahn
ETA	Expected Time of Arrival
IS	Information System
MAD	Mean Absolute Deviation
MSE	Mean Squared Error
MSER	Marginal Standard Error Rule
P&E	Pre- & End-haulage planning department
TEU	Twenty-Feet Equivalent Unit
TS	Tracking Signal
OCL	Customer service digital booking system

1. Purpose of the research

The research was executed for the company Yellowstar Solutions BV and is part of a Bachelor thesis for the study Industrial Engineering and Management. Yellowstar provides IT-solutions for supply chains to increase the chain's efficiency through improvements in communication between chain actors. The main fields of operation of Yellowstar are: distribution and 4th-party logistics, intermodal, offshore, and aviation (Yellowstar, 2017). The research is focused on the intermodal field of operation, with the purpose to identify improvements for the software provided by Yellowstar for intermodal clients. The following sections provide more detailed information on the background of this request for research.

1.2 Problem identification at Yellowstar

The first step regarding the research was the core problem identification at Yellowstar, as explained in the following, on which the whole follow up research is based on.

Yellowstar aims at improving its software for clients operating in intermodal hinterland transport networks. The reasons behind the wish to improve software especially for intermodal clients became clearer after some meetings with employees of Yellowstar, and can be summarized as follows (see also problem cluster in Figure 1). Firstly, employees of clients seem not to use the software consistently, the cause for this issue was not clear during observations at the host company; secondly, it seems like developers had mainly contact with the IT-department of the client, and not as much with the end-users, mainly because of intern time pressure and "too busy" users; thirdly, the client looks very skeptical at the software and whether the benefits are as initially intended. In general, there exists an uncertainty on which parts of the intermodal process and information flows are in which way affected by the provided software, leading potentially to a measurable change in efficiency within the supply chain.

Therefore, the core problem was identified to be an insufficient research on process and information flows at the client, caused by time pressure and lack of meetings with the end-users during the development phase.

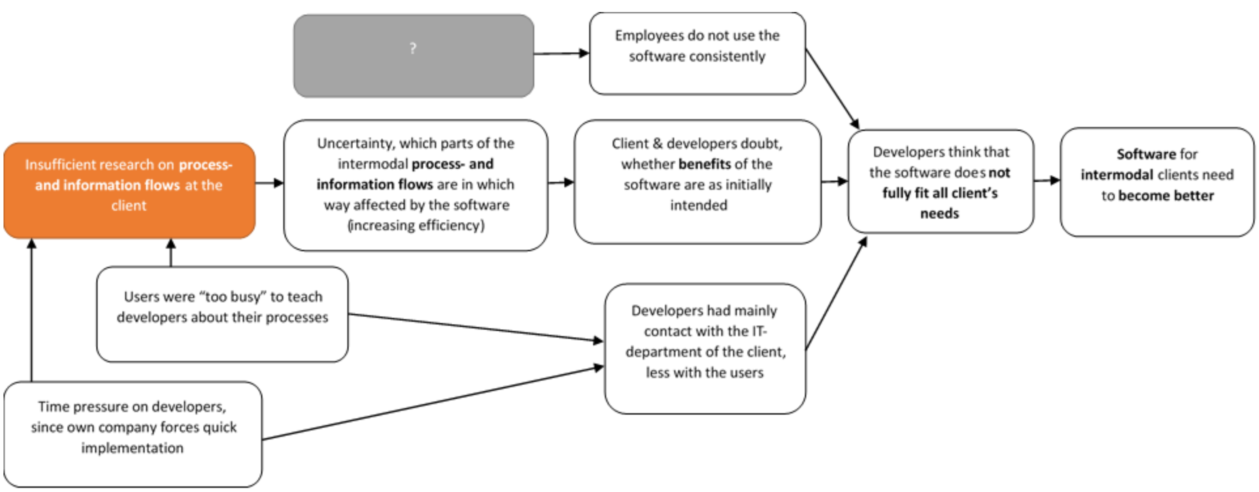

Figure 1 problem cluster Yellowstar

1.3 Problem-solving approach: Yellowstar

Regarding the core problem of the host company, the causes which arose during the development phase of the software cannot be influenced afterwards, but research on the process and information flows of an intermodal hinterland transport system can be done, parameters to measure the performance of the system can be identified, and the impact of improvements through software on these parameters can be measured. The problem was still ill-defined after the observations at Yellowstar, leading to more research on the requirements of the host company, background information on intermodal hinterland transport networks, and information about the intermodal clients of Yellowstar and their needs (see 1.3.3).

1.3.1 Means at disposal

The means that were at disposal for the research are:

- Internal project documentations of Yellowstar
- Interviews with developers and consultants of Yellowstar
- Access to clients' databases via Yellowstar (with permission of the client)
- Option to visit clients (with permission of the client)
- Access to scientific literature databases

1.3.2 Stakeholders of the research

The stakeholders of the research project are the following:

1) Yellowstar top management — project owner, interested in results to improve their products
2) Terminal top management — clients, interested in options for improvement of their business
3) Terminal planners — main users of the information system
4) University of Twente — interested in an academically correct execution of the research

The top management of Yellowstar and of the terminal, and the terminal planners were directly involved in the problem-solving process, since they are direct users or providers of the software.

1.3.3 Solved knowledge problems

Prior to the problem identification for the intermodal client, some knowledge problems needed to be solved to ensure an efficient research that fits the requirements of Yellowstar, and to formulate a suitable research question. The answers to the following knowledge problems can be found in this sub-section:

1) What are the solution requirements of the host company?
2) How is an Intermodal Hinterland Transport System defined?
3) What are main operators and their activities in Intermodal Transport systems?
4) Which parts of the Intermodal Transport System are most crucial for the system's efficiency?
5) Which parameters describe a terminal's efficiency?

(1) What are the solution requirements of the host company?

The research should be related to the requirements and nature of work at Yellowstar. Goals of Yellowstar can be obtained from their mission statement, which says: "Yellowstar wants to make the supply chain and the underlying processes predictable for all supply chain parties through sharing their knowledge and insights in organizations and for people. This will allow companies and employees to become very efficient,

to take right decisions at the right time and to act directly and precisely." (Yellowstar, 2017).
In summary, the research should have a focus on communication aspects between supply chain actors, and on related decision making aspects within the system. The solution should include the predictability of processes and a relation to the chains' efficiency.

(2) How is an intermodal hinterland transport system defined?

To understand what intermodal hinterland transport systems are, first a definition of intermodal transport is given by Lowe (2005) as the "concept of utilizing two or more 'suitable' modes, in combination, to form an integrated transport chain aimed at achieving operationally efficient and cost-effective delivery of goods in an environmentally sustainable manner from their point of origin to their final destination". Lowe also gives some examples on the mentioned different transport modes, which can be: road haulage, rail freighting, airfreighting and shipping, where shipping can be done via short sea shipping (on sea, not crossing an ocean), coastal shipping (on sea along the coast), trans-ocean shipping and inland shipping (along rivers).
As intermodal transport is defined as a combination of transport modes, the freight needs to be transferred from one mode to another. These transfers are performed at terminals with different kinds of lifting equipment. These terminals can be either located at the sea or inland. Inland-terminals are also referred to as 'hinterland terminals'. There exist different forms of terminals, handling different sorts of freight, such as fluids, gas, coal, cars, or everything that can be placed in containers.

(3) What are the main operators and their activities in intermodal transport systems?

Macharis and Bontekoning (2004) provide a general overview on four main operators and their activities in intermodal freight transport. The first group are drayage operators who "take care of the planning and scheduling of trucks between the terminal and the shippers and receivers". The second group include terminal operators, who "take care of the transshipment operations from road to rail or barge, or from rail to rail, or barge to barge". As already seen by Lowe, there exist more modes that can be handled by terminal operators, such as airplanes or other ships that fall not under the category of 'barges'. The third group form network operators, who "take care of the infrastructure planning and the organization of rail or barge transport". In this context, Lowe (2005) uses the term "freight forwarder", who "operates no vehicles, but contracts with relevant intermodal operators on behalf of the shipper". The term 'freight forwarder' can overlap with the fourth group defined by Macharis and Bontekoning, the "intermodal operators" who are "users of the intermodal infrastructure and services" and "take care of the route selection for shipment through the whole intermodal network".

(4) Which parts of an intermodal transport system are most crucial for the system's efficiency?

After defining some main activities within an intermodal transport system (see sub-section 1.3.3 (3)), the scope needs to be reduced by focusing on the part of the system which has most impact on the overall system's efficiency. Following Lowe (2005), intermodal transport needs to become more competitive with shorter distance road transport. An example for competition on short distance transport are hinterland terminals, which lie within a distance of only several hundred kilometers from a sea terminal. Intermodal transport gains a cost advantage against pure truck transport for larger distances, but the shorter the transport distance, the more attractive it becomes to only use truck transport for potential customers, since it offers then quicker transport for the same or less money. Lowe refers to the European Commission that states that terminals determine in large parts the competitiveness and utility of intermodal systems, because they are the "vital interfaces between modes". The efficiency of the terminal determines how quick a journey can be continued.

(5) Which parameters make a terminal's efficiency measurable?

To make the efficiency of a terminal measurable, some parameters need to be defined. These parameters are also needed to formulate the research question and to test possible solutions. A suitable source of parameters is literature about operations research problems in intermodal transport, since operations research is used to optimize systems.
In general, all solutions lead to a minimization of the throughput time of vehicles and goods, which can be described as the sum of waiting times for ships/vehicles or containers at the terminals.
Crainic and Kim (2007) show examples of different problems regarding terminal planning, handling the minimization of travel-times and -distances of terminal equipment, or the turn-around time of ships and land vehicles. These lead to shorter waiting times of vehicles or containers. Examples provided by Macharis and Bontekoning (2004) refer also directly to the minimization of waiting times.
Since there are obviously many ways to minimize waiting times, for example through planning activities like stowage sequencing or berth- and crane allocation (Crainic & Kim, 2007), some observations at a terminal are needed to identify the specific needs of the client of Yellowstar.

1.3.4 Limitations and constraints

Based on the information obtained, some limits and a constraint regarding the research can be formulated. The constraint given by the host company is the following:

a) The research scope should focus on communication aspects between supply chain actors

Limitations based on literature findings and time limitations of the research are defined as:

i. Limit on terminal planning activities that are influenced by external communication
ii. Limit on standard container movements (exclude special goods transport like coal)
iii. Limit on the modalities barge, train and truck
iv. Limit on operational planning activities

2. The research questions

The goal of the research is to define a set of improvements for an information system, which is designed to share information within the whole intermodal transport network, with the aim to increase the system's efficiency through more informed decision making. Since the focus lies on terminals, the efficiency of the system is described as the throughput time of entities at a terminal. Entities of a terminal are in this case: barges, trains, trucks, containers. The main research question can be therefore formulated as follows:

How can the communication within the intermodal hinterland transport network be improved by an Information System (of Yellowstar) to minimize the average throughput time of entities at intermodal hinterland terminals?

The research question can be split up into these sub-questions:

i. Which information shared within the intermodal hinterland transport network is essential for operational planning activities at intermodal hinterland terminals?

ii. In which way is the throughput time of entities at intermodal hinterland terminals correlated to the communication performance within the intermodal hinterland transport network?

iii. How could the Information System for an intermodal hinterland terminal be adjusted to improve the communication performance within the intermodal transport network further?

iv. Which effects could these adjustments have on the average throughput time of entities at intermodal hinterland terminals?

2.1 Open knowledge problems related to the research questions

To answer the research questions, the following knowledge problems still need to be solved during research at a terminal:

1) How do the process and information flows within the intermodal transport system look like?
2) What is planned at the operational level at terminals?
    a. Which information is needed?
    b. From whom is this information needed?
    c. When is this information needed?
    d. How is the information transmitted?
3) What effects can operational processes have on other processes at the terminal?

3. The research design

In this section, the general execution frame of the research is described. This research is executed as a descripto-explanatory (Section 3.1) case study under field conditions (Section 3.3). More information on the research population, and the methods of data gathering and analysis can be found respectively in Section 3.2, Section 3.4 and Section 3.5.

3.1 Type of research

This research is executed as a descripto-explanatory study (Saunders, Lewis, & Thornhill, 2009). First, a clear picture of the situation at the intermodal terminal and the related transport network is generated. Thus, the first result is a detailed description of the process and information flows. Based on these insights, an explanatory research follows to determine and understand potential relationships between communication performances within the system and the terminal's efficiency. To test these relationships and effects of adjustments on the system, the hinterland transport network is simulated.

3.2 Research population, subjects and objects

The research population includes planners of terminal activities, users of the IS who provide input to the system, and users who work with the output of the planning activities. These are the people who are involved in the communication process of the system, and who run the terminal based on this communication. The main research subjects were the planners of the terminal, due to their central role in transforming information within the IS. The containers and vehicles themselves were research objects, since their movements result from the activities of the research population, and the analysis of these movements forms the basis to measure the efficiency of the terminal.

3.3 Research strategy

Due to time restrictions, this research has the nature of a case study under field conditions by focusing on the analysis of one company. Therefore, it should not be assumed that the results are fully generalizable. Furthermore, the research has characteristics of an embedded case (Saunders, Lewis, & Thornhill, 2009), since the focus of the research lies only on several single departments, and not on the complete system or company, excluding for example activities of the human resources department.
The case study is part of a Grounded Theory approach (Glaser & Strauss, 1967). Following the approach, qualitative and quantitative data of the case study were used to develop a theory, which was then tested within a simulation to assess the validity and the usefulness as a solution for the research question.

3.4 Methods of data gathering

For the descriptive part of the research, getting a picture of the real planning/process and information flows, interviews with relevant managers and key users were used. With the researcher in the role of an 'observer as participant' (Saunders, Lewis, & Thornhill, 2009) at different departments of the terminal, it was possible to validate and complement the qualitative data from the interviews. Because the network of users of an information system can be very complex and not all relevant users are known in the beginning, an iterative approach of stakeholder identification was followed, like it was suggested by Pouloudi and Whiteley (1997). They suggested the following steps to identify stakeholders in inter-organizational systems:

1) Interview 'obvious' stakeholders
2) Expand interviews to understand the role of the stakeholder, their relationships to each other, and to identify further stakeholders
3) Read literature about the environment of research
4) Identify stakeholders who have only an indirect impact on the system

This research started at the main contact person at the terminal, who is a top manager and an 'obvious' stakeholder of the system. An interview led to other stakeholders, who then provided hints for more stakeholders, and so on. It is decided that the search for stakeholders ends at the point at which all stakeholders with a direct impact on the system are observed, since this research has a focus on stakeholders taking part in active communication within the network for terminal planning purposes. Therefore, the last point of Pouloudi and Whiteley was excluded for this research.

For the explanatory part, mainly data that was already available at the terminal or accessible via the servers of Yellowstar is used. After getting the permission of the customer to use the data, and the access to historic data of the information system, the data will be exported for further analysis.

3.5 Methods of data processing and analysis

First, the data of the interviews and observations are merged in process maps. These process maps are then analyzed to detect critical paths of information transfer, and the nature of this critical information. The second step is to analyze in which way the terminal's efficiency is correlated to the time and level of information fulfillment for these paths. Finally, some potential improvements to the system are tested within a simulation environment, to identify effects on waiting times of vehicles or containers.

4 Research at the intermodal client

In this section, the case study selection (Section 4.1) and observation results (Section 4.2) are presented. A summary of solved knowledge problems based on the observation results, and a related problem cluster is given respectively in Section 4.3 and Section 4.4. From the problem cluster, hypotheses regarding process improvement options are derived in Section 4.5 and translated into forecast scenarios to be tested with the simulation (Section 4.6).

4.1 Selection of intermodal client

Yellowstar has several multimodal clients, but based on time restrictions of this research, one client was selected for a case study. The client who accepted a cooperation request was 'Neska Schifffahrts- und Speditionskontor GmbH'. Neska runs five tri-modal (barge, rail and truck modalities) hinterland terminals in Germany along the Rhine, and mainly provides barge and train transport services between the ports of Rotterdam or Antwerp and their hinterland terminals. The barges are operated by the company 'Alcotrans', which is also part of the Neska group. Neska has the largest intermodal network of all intermodal clients of Yellowstar. For this research, access to the largest terminal of Neska, the CTS in Cologne, was permitted.

4.2 Observation results: General process of an intermodal voyage

Before looking in detail at observations at different departments of the terminal, a general idea of the main processes to be undertaken for a complete intermodal voyage are given. The main steps of an import barge voyage from the port of Rotterdam to the hinterland Terminal CTS in Cologne are as follows:

1) A container arrives at the port of Rotterdam. The customer who booked the container requests a voyage to a destination address in Germany directly at the hinterland terminal. The request may come along with some restrictions regarding arrival time at the hinterland terminal (inland closing date), or the arrival time at the final destination.

2) The hinterland terminal checks the booking request of the customer. If the destination address lies within the terminals operation radius, the request with the preferred voyage is forwarded to the barge operator (Alcotrans). Alcotrans can accept the request or select another voyage which lies within the defined time restrictions.

3) During the voyage, Alcotrans sends multiple times Excel files to the terminals, with information on expected arrival times for each terminal on the barge's route.

4) At 2 pm the day before the planned arrival of the barge, the terminal uses ETAs from the barge operator to request a suitable amount of crane operators for the next day shifts.

5) About 1 to ½ day prior to arrival of the barge, Alcotrans sends a delete list to the affected terminal. This list contains information on how many and which containers must be unloaded at the terminal.

6) With the delete list received, the terminal creates a list of 'jobs' for the cranes which will operate the arriving barge. This list shows the crane operators which containers they should move when

to which location.

7) After the barge arrives at the terminal, the delete list is transmitted again and checked by the terminal. If the barge needs not only to be unloaded, but also to be loaded, a loading list was previously transmitted to the barge captain, who created a stow plan (where to place which container onto the barge). Information of the stow plan is then included in the job list of the cranes.

8) The cranes load and unload the barge, and the barge leaves the terminal after all jobs are done.

9) The container waits in the yard of the terminal until its disposition to the final destination via truck is planned and executed.

The steps for an export voyage, where containers are requested to be moved to a sea terminal, are comparable to the ones for an import voyage, with the difference that the container voyage starts at an inland address.

A detailed report on all observations at each department can be found in Appendix 2. In the following Section 4.3, only the relevant findings to solve the knowledge problems are presented.

4.3 Solved knowledge problems through terminal observations

After finish observations at the terminal, some open knowledge problems could be answered:

(1) How do the process and information flows within the intermodal transport system look like?

Section 4.2 gave a general overview, as well as detailed descriptions per relevant department, on the main process- and information flows, with a focus on the intermodal terminal. Since the complete structure of the interlinked processes is relatively complex, a process map based on the BPMN 2.0 standard was created (see Appendix 3) to get a clearer picture of the interconnections.

(2) What is planned on operational level at terminals?

a) Which information is needed?
b) From whom is this information needed?
c) When is this information needed?
d) How is the information transmitted?

From the observations at the CTS it can be derived that the terminal has mainly four operational tasks to execute, thus tasks that include a near day-to-day planning. These tasks are:

i. The rescheduling of containers to earlier voyages by the B&R department. Main information needed are the time and modality restrictions of containers, provided by the customers, and the capacity restrictions of barges, provided by the barge operator. The information on capacity restrictions comes along with the request of the barge operator for rescheduling. The restrictions regarding the containers are stored in the CMS during the initial booking of the container voyage.

ii. The request of crane operators for the next day shifts by the Control Station. The main information needed are precise ETAs of barges and trains arriving at the next day. The information is provided by the barge operator via the B&R department. It is needed in a calendar format and transmitted via the connection of the BMS and CMS, and manually via mail including an excel file. The B&R department transforms this information in a calendar format.

iii. The creation of job lists for cranes and reach-stacker by the B&R department. The main information needed are the final load- and delete lists, and the stow plan. The delete list and stow plan are provided by the barge operator via the barge captain, the load list is available via the CMS. The information is needed at the arrival of the barge or train and mainly transmitted digitally.

iv. The assignment of container disposition orders to trucks by the Disposition department. The main information needed here are time restrictions of containers, and ETAs of barges and trains. The time restrictions are visible within the disposition lost, which contains all information on container disposition orders. The ETAs of barges and trains are provided by the barge operator via the B&R department. The ETAs are transmitted via the connection of the BMS and CMS, and manually via email including an Excel file. The B&R department transforms this information in a calendar format. The information is needed one day before the planned disposition of a container.

By solving the knowledge problems above, the first sub-research-question: "Which information shared within the intermodal hinterland transport network is essential for operational planning activities at intermodal hinterland terminals?", is also answered.

(3) What effects can operational processes have on other processes at the terminal?

All decisions made during operational planning may affect other processes at the terminal, leading to a direct impact on the performance of the terminal. From the process map and observations, some relations can be assumed.

Looking first at the rescheduling of containers to an earlier voyage, it will affect mainly the throughput time at either the hinterland terminal, or the sea terminal. If an earlier export voyage is selected, the container will leave the hinterland terminal earlier, but needs to be stored longer at the sea terminal. In the case of an earlier import, the container will arrive earlier at the hinterland terminal, but needs to wait for its preplanned disposition slot. In both cases, it may affect the yard planning, and therefore the processing times of cranes when a rescheduled container is not directly reachable. A longer crane processing time also has a direct effect on vehicle throughput times at the terminal.

By looking next at the request of crane and reach-stacker operators for the next day, it is logical that this has a direct effect on the available crane capacities, and therefore also on the throughput times of vehicles at the terminal. For example, if a barge arrives during an earlier shift than predicted and since the arrival was not planned, only one of two available cranes is available for processing, the throughput time of the barge is expected to be doubled. Furthermore, arriving trucks need to be handled parallelly, leading to even longer waiting times for all vehicles.
An insufficient planning of crane operators, due to unreliable ETAs, leads not only to longer throughput times at the related hinterland terminal, but also to the same problem at follow-up terminal stops. Additionally, large deviations from the expected arrival time may also lead to a more inefficient yard planning and a shift in the disposition planning.

Another operational task is the creation of crane and reach-stacker job lists. The creation of such lists should be linked to the yard planning, since unnecessary extra movements to reach containers should be avoided. An inefficient job list leading to extra container movements can therefore also lead to longer throughput times of vehicles at the terminal.

The last operational task to be considered is the assignment of container disposition orders to trucks. The assignment itself may not affect other processes that much, since the planning of disposition slots and the related yard planning is already done days or weeks before the actual disposition takes place.

4.4. Problem description Neska

After having finished the observations and interviews at the CTS terminal and solving the open knowledge questions, a problem cluster (Figure 2) was created, identifying the main problems at the terminal in the context of supply chain communication. A general issue at the terminal is that the terminal's operations planning often does not fit reality. This applies on the one hand to the allocation of crane operators, which is often not in line with the arrival times of barges or trains, or to shifts in end haulage operations, leading to peak utilizations of cranes and trucks. On the other hand, large changes of loading lists shortly before arrival of barges or trains also have an impact on the workload at the terminal. This is mainly because major clients, who have booked fixed contingents for most voyages, communicate greater amounts of container cancellations only several hours before the arrival of a barge or train.

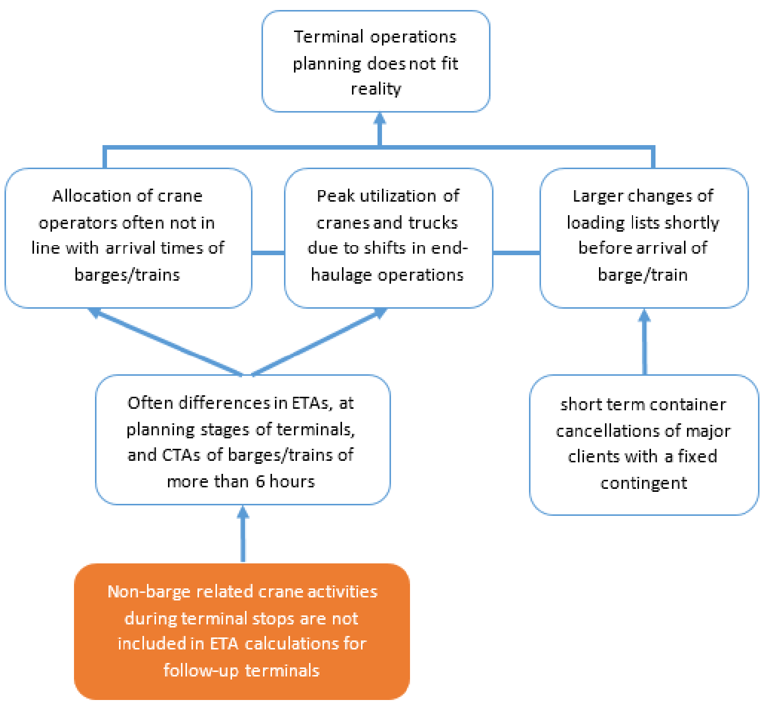

Figure 2 problem cluster Neska

Of all these issues, the wrong allocation of crane operators and the peak utilization of cranes and trucks could be identified as the main cause for a weaker terminal operations performance, since it is assumed that this part of the operational planning has the largest effect on vehicle throughput times, like explained in Section 4.3. The causes of these issues lie in large differences in the communication on expected times of arrival (ETAs) of barges and trains during the planning stages of the terminal, and their current times of arrival (CTAs), referred to as forecast error. The allocation of crane operators for a day is defined one day before at 2 pm. The ETAs communicated by barge operators until this deadline differ often up to six hours from the CTAs of the barges, as described by employees at the terminal. This leads to the situation that barges arrive within later or earlier crane operator shifts than intended. In this case, not enough crane operators may be available to fully utilize the lifting equipment, or too many operators are available when they are not needed.

In conclusion, there is obviously a problem with the calculation and communication of ETAs of, mainly, barges. One reason behind this may lie within the information shared between supply chain actors to calculate the ETAs. The ETAs are provided by the barge operator. The ETA for a given terminal is in general the sum of barge throughput times at previous terminals, and travel times between these terminals. The travel times are relatively fixed, since there are normally no unexpected distortions on a river. The minimum throughput time of barges at a terminal depends on the total time needed for a crane to finish all container movements during a barge berth. In the special case of an intermodal hinterland terminal, cranes do not exclusively handle barges, but also trains and trucks which arrive while a barge is operated. But the only information that the terminals communicate with the barge operator, one day before the arrival of the barge, is the number of containers they intend to load onto the barge. Therefore, the total workload of a terminal, which is crucial for the total barge operation time, seems not to be included in the calculation of ETAs.

4.5 Problem-solving approach: hypotheses

Since the core problem points to an insufficient calculation of barge throughput times at terminals, the problem-solving approach will focus on the evaluation of a suitable forecast method. The forecast for hinterland terminals, where cranes are used for parallel processing of multiple modalities, seems to be a very special case within literature about Operations Research for intermodal terminals. Most of the literature is assuming terminals with cranes that handle only barges, leading to relatively simple calculations of throughput times. To be able to estimate the total workload of all parallel processing hinterland terminals that a barge will visit during 24 hours, parts of the idea behind the approach of Sideris et. al. (2014), will be used. This includes estimates of daily container movements at a terminal based on arrival and distribution patterns of containers prior and after a vessel's arrival. Such an estimation of the workload could be done by the terminals itself, leading to an extra communication link between the terminals, but making them more independent from the barge operator.

From the problem description for the terminal (Section 4.4) the following hypotheses for an improvement of the terminal's information system can be derived:

1) Including a prediction of all crane operations at terminals, within an intermodal hinterland network, in ETA calculations of barges decreases the forecast error for barge arrival times significantly.
2) A decreased forecast error for barge arrival times has a significant effect on a decrease in throughput times of transport vehicles and containers at a terminal.

These hypotheses are tested using a simulation of the intermodal hinterland transport network.

4.6 Problem solving approach: barge ETA forecast variations

To test hypothesis 1), three forecast variations for barge ETAs are analyzed, each dealing with different combinations of input data from modalities with influence on the crane workload at terminals.
The first described forecast scenario represents the real situation regarding barge ETA calculations within the network ("vehicle only"). In the actual situation, the barge operator and the terminals exchange information on the expected total number of barge import and export containers which need to be processed. Since observations at the terminal showed that the amount of train and truck containers to be processed simultaneous to the barge are not shared among the barge operator and the terminals, these

two factors are also excluded for the given forecast scenario. Based on this information, the expected barge throughput times at all to be visited terminals is estimated. Finally, with the fixed inter-terminal travel times known and added to the throughput times, the barge ETAs for each terminal are shared among all terminals along the barge's route (Figure 28).

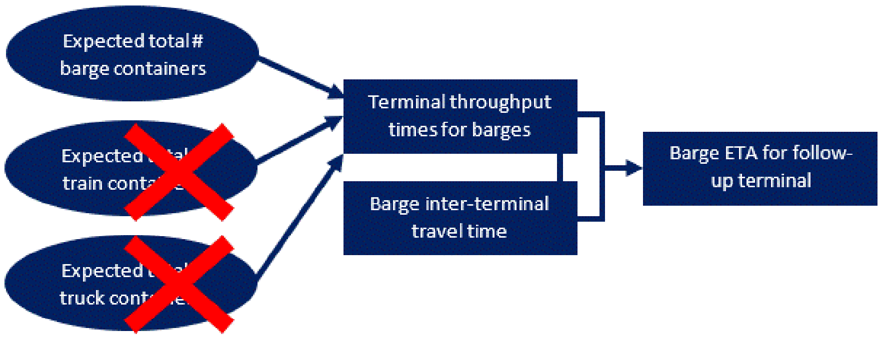

Figure 28 scheme standard forecast ("vehicle only")

The second scenario ("all TEUs") is intended to follow hypothesis 1), to include a prediction of all crane operations at a terminal, by also sharing information on the expected total number of truck and train containers during a barge berth at a terminal (Figure 29). Since trains are not explicitly operated by cranes, but mainly by reach stackers, a third scenario ("gate barge") is set up that excludes the expected amount of train containers from the ETA calculation (Figure 30).

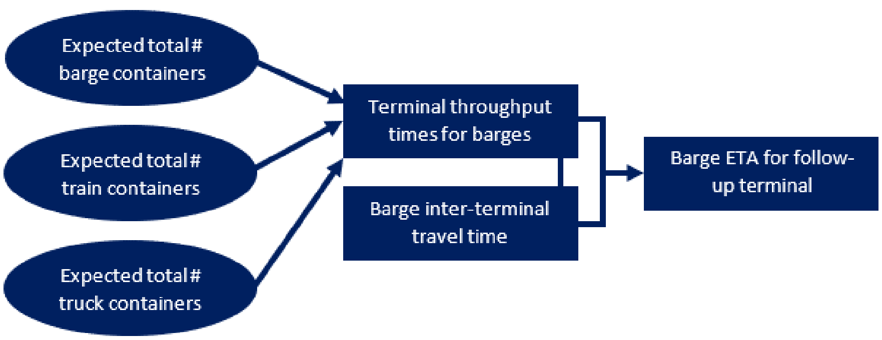

Figure29 scheme forecast 2 ("all TEUs")

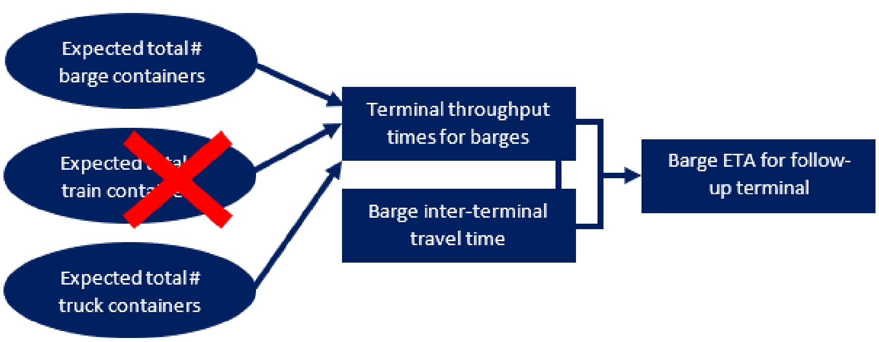

Figure 30 scheme forecast 3 ("gate barge")

5. Simulation of an intermodal hinterland transport network

To be able to test the hypotheses, a model of the hinterland transport network is designed, which is then used for simulation. The software used is 'Siemens Tecnomatix Plant Simulation 11', chosen mainly due to licensing and familiarity reasons, and because of the flexible toolsets for discrete event simulation, which this software provides. Plant Simulation 11 provides modules for the modelling of transport activities, for workforce management, and different queue systems. A multi-terminal transport network can be simulated with these modules. The following sections provide information on the design of the model, the input data, the model validation, and results from scenarios to test the hypotheses.

5.1 The conceptual model

The conceptual model is described in this section by defining the general project objectives, scope and factors, as well as the expected technical outputs. Derived from the terminal observations and analysis in the sections before, it is intended to test the hypotheses from section 4.5 with barge forecast scenarios of section 4.6 as experimental factors.

5.1.1 Modelling and general project objectives

The modelling objective is to test the following two hypotheses:

1) Including a prediction of all crane operations at terminals, within an intermodal hinterland network, in ETA calculations of barges decreases the forecast error for barge arrival times significantly.
2) A decreased forecast error for barge arrival times has a significant effect on a decrease in throughput times of transport vehicles and containers at a terminal.

The general project objectives are:

Time-scale:	4 weeks
Flexibility:	ETA forecast method should be able to be adjusted easily; provide simple access to input parameters to be able to adjust the relatively complex system easily (also option for future usage)
Run-Speed:	Minimum two longer experiments need to be run
Visual display:	2D is sufficient
Ease-of-use:	intended for use by modeler and for presentation, limited possibility for further usage (licensing)

5.1.2 Model outputs/responses

Outputs (to determine achievement of objectives)

- Frequency diagram of forecast errors
- Frequency diagram of waiting times of transport vehicles (barge, truck)
- Frequency diagram of waiting times of containers
- Frequency diagram of processing times of barges
- Frequency diagram of system throughput time of scheduled barge voyages

All frequency diagrams with mean, standard deviation, minimum and maximum.

Outputs (to determine reasons for failure to meet objectives)

- Percentage of barge arrivals outside intended crane shift
- Average number of import and export containers per voyage
- Throughput time of scheduled barge voyages

5.1.3 Experimental factors

The forecasting method for the barge ETAs will run with and without information on non-barge related crane operations at all terminals. The used forecast methods are introduced in section 4.6 and the calculations are explained further in Section 5.4. It will be not tested on other factors, since the research is restricted to communication factors of the intermodal network (Section 1.3.4) and this simulation has the intention to aid the testing of the hypotheses (Section 4.5), with the factor "communication on workload" identified before (See problem cluster in section 4.4).

5.1.4 Model scope

The model scope is based on a literature review on intermodal terminal simulations, observations at the CTS, and options available within the simulation software. Detailed lists of elements included in the model, due to the selected model scope and detail, can be found in Appendix 4.

5.1.5 Level of detail: transport network

The point that makes the model somewhat more complex, is the need to simulate multiple terminals as a transport network. Modelling only one terminal is not sufficient, since the terminals of the network are so close to each other, that a barge will visit several terminals after ETA calculations and crane workforce planning is finished. Furthermore, it is assumed that the forecasts of terminal throughput times are the key to improve the arrival forecasts, and therefore, multiple terminals are modeled. The main terminal network of Neska consists of five terminals, three of which operate with more than one crane and with more than 100 trucks.

To reduce the complexity of the model, only the three larger terminals are modelled. The first one with one crane, the second one with two, and the last one, representing the observed CTS, with three cranes, where the terminal is divided into an area with two cranes for the processing of containers intended for Rotterdam, and an area with one crane for Antwerp.

Another point that increases complexity is the fact that each terminal is connected to the internal barge and train network, but serves also some individual networks to external terminals and sea ports. To reduce the complexity, only the internal barge and rail network is modeled. Theoretically, findings from this network could be expanded to other networks in the future. The first terminal and the Antwerp-part of the last terminal are only connected to the barge network, the other terminals also have a connection to the train network.

5.2 General model description

After defining the frame of the model in section 5.1, the actual modelled transport network and terminals are described in detail in this section. Starting with the transport network as a whole in section 5.2.1, leading to a more detailed view to the terminal construction in section 5.2.2.

5.2.1 Model objects: transport network

The model consists of two parallel transport networks, one for barges and one for trains (Figure 3). The networks are separated into stop locations at terminals, and travel segments between the terminals. The separation of the segments enables barges and trains to pass each other when needed. In general, barges stop at every terminal and need to wait when a berth is occupied. Trains stop either at terminal 2 ('RailStop2' & 'Railstop21') or at terminal 3 ('Railstop3') based on their predefined weekly schedule. Therefore, the train network shows some additional connections to allow trains to pass a terminal without a stop. The length of the individual segments is not equivalent to their simulated length. For example, the short segments to the left (e.g. 'WaterWay01') represent the connection to the sea port, which is the longest connection of all. The length of the individual segments is estimated with routing tools of Google MyMaps (Google MyMaps, 2017). The stop locations have sensors, marked with red lines, which are used to trigger actions at a terminal.

Additionally, each network has a source and a drain that creates barges and trains, respectively, or deletes them. Vehicles are created based on a fixed weekly time scheme and initially loaded with containers for different terminals, based on distributions. Furthermore, destination terminals are defined for the created vehicles, and arrival forecasts for all terminals of a train are calculated, since trains leave the network too quick to be processed by periodical daily forecasts.
After leaving the sea port ('source'), vehicles stop at the next destination terminal stop segment, are loaded and unloaded by the terminal, and reach the sea port again ('drain') after visiting all destination terminals. By reaching the sea port ('drain') vehicles leave the network, but some information on travel time and load of the vehicles is stored.

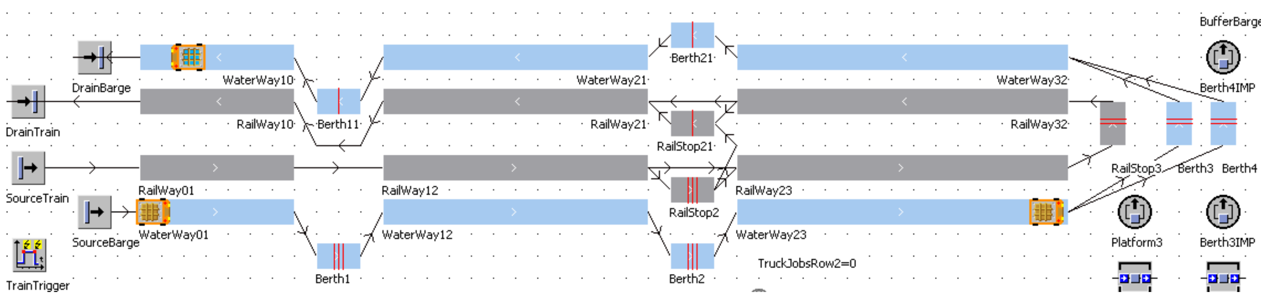

Figure 3 model objects: transport network

5.2.2 Model objects: terminal

The model consists of three terminals, with one terminal having two separate areas, one handling barges from Rotterdam, the other barges from Antwerp. Figure 4 shows the largest terminal with two areas, one below the berth segments and the rail stop, and one above. Each terminal has a berth segment and a transfer station (e.g. Berth3IMP), which transfers import container of an arriving barge to the barge buffer of the terminal, where containers wait for further crane processing. If the terminal has access to the train network, the described objects above are duplicated for trains.

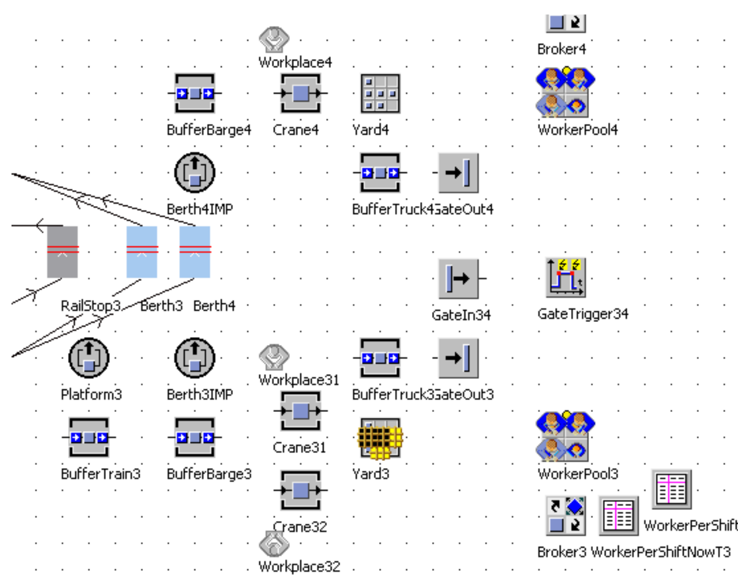

Figure 4 model objects: terminal

After cranes processed a barge or train container, a dwell time, based on a distribution, is assigned to this container, and it is stored in the yard. After the dwell time is over, the container is pulled to the truck buffer and waits for a crane, which transfers it to the gate ('GateOut'). This process represents a container pickup action of a truck: the container waiting in the truck buffer represents a truck waiting for a container. The same is valid for the other case, where a container (truck) enters the terminal via the gate, where a future voyage is assigned to it, and waits in the yard for the intended barge or train. The creation amount and interval of containers is based on hourly distributions. Furthermore, there are distributions based on dwell times before voyages to assign created containers to a future voyage.
If a barge or train arrives and triggers an export sensor, all containers intended for this barge are pulled from the yard to the barge/train buffer, where they wait for cranes loading them onto the vehicle. The barge/train waits until the buffer is empty, plus a dwell time of 15 minutes to ensure that all containers are loaded, before it departs. The process flow is visualized in Figure 31.

Looking next at the cranes, each of them is connected to a workspace. A crane can only operate when the workspace is occupied by a worker. Workers are provided for three different shifts per day, based on a forecast. When a container enters a crane, a worker is requested and processing starts after the worker arrives, or a worker is already available at the crane.

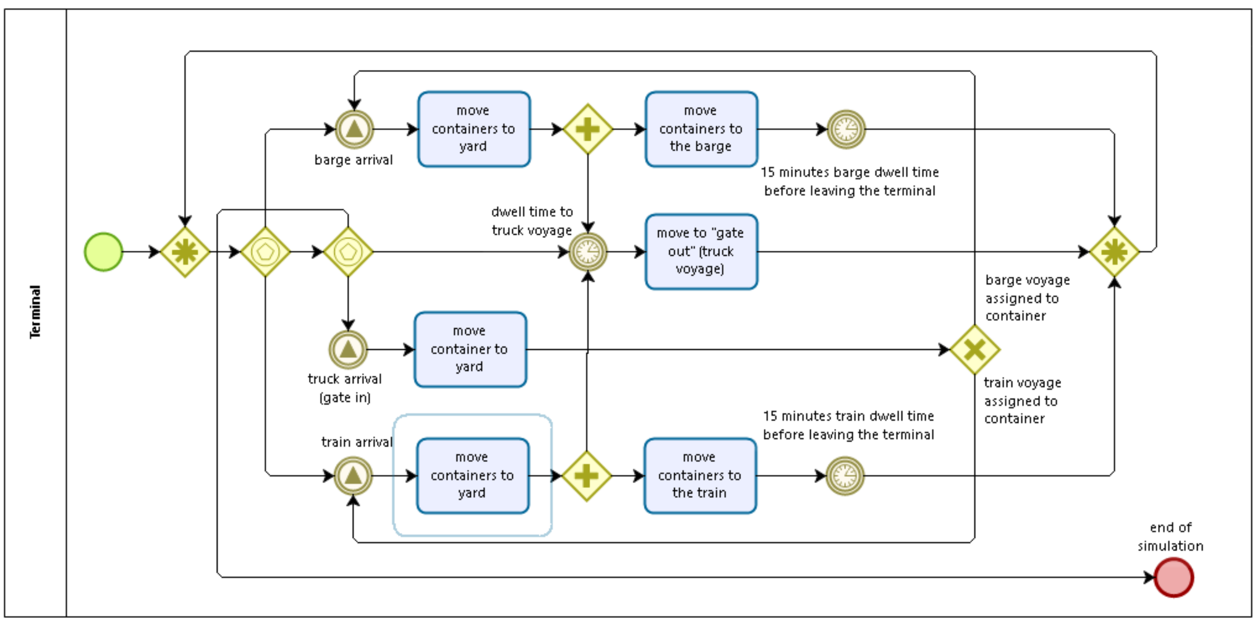

Figure 31 process flow: crane activities and trigger

5.3 Model input parameters

Some input parameters need to be defined to make the model running. In this section, input parameters are described in detail for the behavior and attributes of barges (Section 5.3.1), trains (Section 5.3.2), cranes (Section 5.3.3), containers (Section 5.3.4), and worker shifts (Section 5.3.5).

5.3.1 Model input parameters: barge

Barges are created based on a fixed weekly schedule. The schedule and the number and type of barges are based on the matrix of expected arrival times for the first hinterland terminal within the network. Since the barges start at the sea terminal of Rotterdam or Antwerp, a fixed travel time between the sea and the first hinterland terminal is calculated and subtracted from the ETA to gain initial departure times, and therefore creation times for barges. The creation input values for the trigger of the barge source can be seen in Table 1, with five barges serving Rotterdam and two serving Antwerp. It is important to differentiate between the types of barges, because destination ports differ per barge based on their start terminal. For example, at terminal 3, berth 3 is reserved for barges from Rotterdam, and berth 4 for the ones from Antwerp (see Figure 4). Some uniform variation in departure times between 1 and 60 minutes (60 and 3600 seconds) is added to the creation parameters, since observations indicate that barges do not always depart on time from the sea terminals. It is known from interviews at the terminal that there exits some variation in departure times at sea terminals, but there is no reliable data available to derive a distribution for this variation. Therefore, the selected span of 1-60 minutes delay at sea terminals is only an assumption to add some variation to the model without forcing a major impact to the system.

Table 1 creation scheme barges

Point in Time	Value
01.01.2017 21:00:00.0000	1,.MUs.BargeRot,uniform,60,3600
02.01.2017 13:00:00.0000	1,.MUs.BargeRot,uniform,60,3600
03.01.2017 20:00:00.0000	1,.MUs.BargeAnt,uniform,60,3600
04.01.2017 09:00:00.0000	1,.MUs.BargeRot,uniform,60,3600
06.01.2017 17:00:00.0000	1,.MUs.BargeRot,uniform,60,3600
06.01.2017 23:00:00.0000	1,.MUs.BargeAnt,uniform,60,3600
07.01.2017 11:00:00.0000	1,.MUs.BargeRot,uniform,60,3600

Table 1 shows all input parameters for the creation of barges at sea terminals ('source'). The first column defines the weekday and time for a barge to start at the sea terminal. The starting point of the simulation is set to the first of January 2017 with a barge starting at 9pm. The second column defines the amount of barges starting at this point in time (1), the type of barge ('BargeRot' for barge from Rotterdam or 'BargeAnt' for barge from Antwerp), and a uniform start delay between 60 and 3600 seconds. The schedule defined by Table 1 is applied for every week until the simulation stops.

Furthermore, barges travel with different speeds based on the direction they travel. If they are traveling with the flow of the river, during the export voyage, they move with a speed of 4,9 m/s (about 9,5 knots). Against the flow of the river, the speed is about 2,9 m/s (about 5,6 knots). The travel speed parameters are estimated with the help of the website Marinetraffic.com (Marinetraffic.com, 2017), a website for live tracking most of the operating ships worldwide, and a barge travel report in a local magazine (Maurutto, 2016).

Finally, it is assumed that barges have unlimited capacity to reduce complexity. Since container creation is based on distributions derived from the real system, extreme unrealistic values for the load of a barge is not expected.

5.3.2 Model input parameters: train

Table 2 creation scheme trains

Point in Time	Value
02.01.2017 00:30:00.0000	1,.MUs.Train23,uniform,1,7200
03.01.2017 04:30:00.0000	1,.MUs.Train3,uniform,1,7200
03.01.2017 04:40:00.0000	1,.MUs.Train2,uniform,1,7200
04.01.2017 00:30:00.0000	1,.MUs.Train23,uniform,1,7200
05.01.2017 04:30:00.0000	1,.MUs.Train3,uniform,1,7200
05.01.2017 04:40:00.0000	1,.MUs.Train2,uniform,1,7200
06.01.2017 00:30:00.0000	1,.MUs.Train23,uniform,1,7200

Train parameters are defined in a similar way like described in section 5.3.1 for barges. The creation parameters can be seen in Table 2. From observations, uniform deviations from the scheduled creation time between 1 second and 2 hours are assumed. Trains travel with a constant speed of 17 m/s (assumption). Furthermore, there exist two different types of trains: firstly, the trains of type “Train23” are created on Mondays, Wednesdays, and Fridays and stop at terminals 2 and 3; secondly, on Tuesdays and Thursdays, two trains with only one, but different destinations are created (“Train2” with destination terminal 2, and “Train3” with destination terminal 3).
The trains have different capacities, extracted from official arrival schedules of the terminal. The trains of type “Train23” have a capacity limit of 99 containers, where other train types are restricted to 24 containers.

5.3.3 Model input parameters: crane

The main crane input parameter, which is described in this section, is the distribution for its processing time (Section 5.3.3.1). Furthermore, cranes need to handle different modalities simultaneously. Therefore, some rules are needed to ensure that no unrealistic long waiting times can occur (Section 5.3.3.2).

5.3.3.1 Basic input parameters

Cranes only require a very limited number of parameters, with the crane processing time as the most important one, besides capacity limits. They are single processors, handling only one entity within a defined processing time. To determine the processing time, the given historic data for crane jobs needed to be filtered on jobs that lie in a period where cranes are assumed to be fully utilized. It is assumed that these periods are processing periods where barges or trains are continuously processed. The data is therefore filtered manually on all jobs that lie definitely within a barge or train processing period. To determine the crane processing times, the times between two stop times of jobs is calculated.

As a next step, the distributions are fitted to the examined data using the software XLSTAT, and by verifying the fitted results with the internal fitting tool of Plant Simulation 11. Following the fitting results (Tables 3 and 4), no distribution fits within statistical significant parameters (observed Chi-square values: 1261 > 28; 332 > 28 and p < 0,00). It is decided to observe two distributions based on their visual fit: the Log-normal (Figure 6) and the Erlang (Figure 5) distribution. The output of the fitting and tests are summarized in tables 7 (Erlang) and 8 (Log-normal).

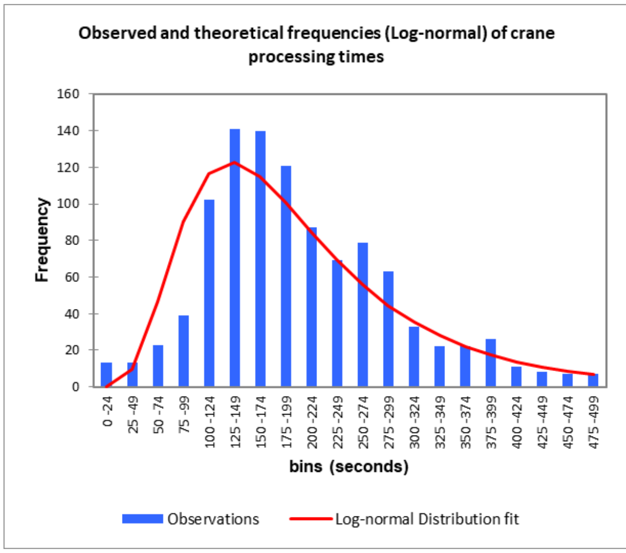

Figure 6 crane Log-normal distribution fitting

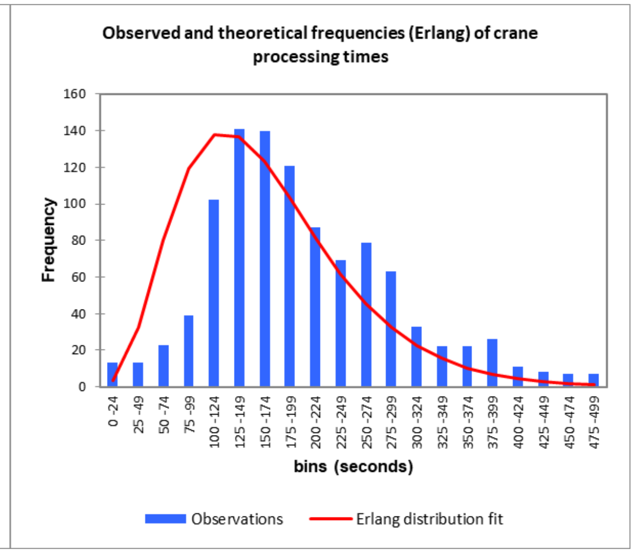

Figure 5 crane Erlang distribution fitting

Chi-square (Observed value)	1261,732
Chi-square (Critical value)	27,587
DF	17
p-value	< 0,0001
alpha	0,05

Chi-square (Observed value)	331,580
Chi-square (Critical value)	27,587
DF	17
p-value	< 0,0001
alpha	0,05

Statistic	Data	Parameters
Mean	200,433	205,754
Variance	8214,177	14283,884
Skewness (Pearson)	0,719	1,939
Kurtosis (Pearson)	0,416	7,350

Statistic	Data	Parameters
Mean	200,433	163,929
Variance	8214,177	6718,167
Skewness (Pearson)	0,719	1,000
Kurtosis (Pearson)	0,416	1,500

Comparing the test values of the distributions, the Erlang distribution has a better observed Chi-square value than the Log-normal distribution (observed: 331,6 VS 1261,7), but both are not below the critical value (critical: 27,6). Therefore, it could be assumed that the Erlang distribution should be chosen. Continuing then with the visual comparison of the distributions, the Erlang distributions seems to provide a better fit around the mean, but it is expected that the use of the Erlang distribution will lead to significant more appearances of shorter crane processing times compared to the reality. This could lead to problems during validation of the model, and therefore also the results. The Log-normal distribution does not fit the mean as well as the Erlang distribution, but provides a significant better fit for lower values. Therefore, it is decided to use the following processing time parameters for all cranes: Log-normal distribution with Mu = 206 seconds, sigma = 120 seconds, lower bound = 20 seconds, upper bound = 500 seconds.

5.3.3.2 Crane processing rules

As described in Section 5.2.2, containers can enter cranes from different queues with different destinations. Therefore, some rules need to be defined for crane processing. In general, requests from containers representing truck movements have priority, thus container request from the truck buffer to leave the terminal or to enter the yard. In result, if containers from different queues could be processed next by a crane, it will be chosen to process the one from the truck queue. To avoid the unrealistic situation that barges are not processed at all for a longer period, a rule is added to switch priority to either a barge or train queue when the last three or more crane jobs in a row were truck jobs.

5.3.4 Model parameters: container

Containers may enter the network on three different ways: firstly, they are created with a barge; secondly, they are created with a train; thirdly, they enter a terminal via a gate. The following sections describe the creation parameters for the different creation situations of containers.

5.3.4.1 Parameters container creation: barge

Newly created barges will visit all terminals, and therefore a given number of containers for all terminals need to be created, relative to the size of the destination terminals. The created containers are named after their destination terminal (e.g. TEU1 for destination terminal 1). To gain a general idea on which distribution is suitable to represent all container creation processes for barges, all barge voyages, which could be identified as periodical voyages, are analyzed based on their number of loading and unloading crane jobs. In result, there is a choice between the Erlang (Figure 7) and Log-normal (Figure 8) distribution.

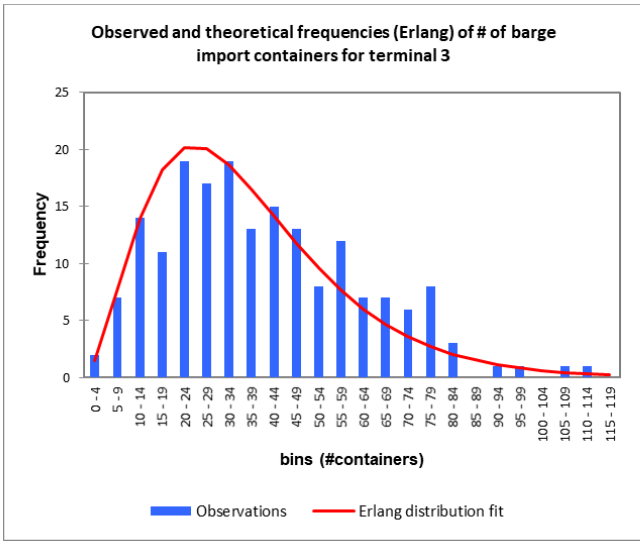

Figure 7 container creation barge Erlang distribution fitting

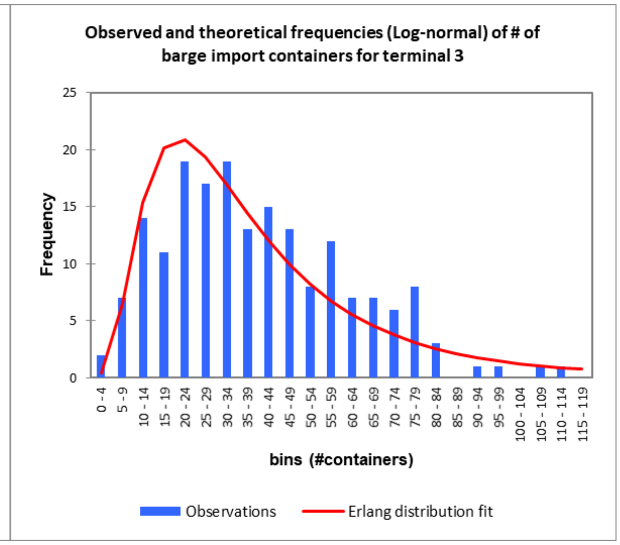

Figure 8 container creation barge Log-Normal distribution fitting

Table 6 container creation barge Erlang distribution parameters

Chi-square (Observed value)	25,075
Chi-square (Critical value)	32,671
DF	21
p-value	0,244
alpha	0,05

Statistic	Data	Parameters
Mean	39,486	36,877
Variance	485,382	453,305
Skewness (Pearson)	0,652	1,155
Kurtosis (Pearson)	0,000	2,000

Table 5 container creation barge Log-normal distribution parameters

Chi-square (Observed value)	31,539
Chi-square (Critical value)	32,671
DF	21
p-value	0,065
alpha	0,05

Statistic	Data	Parameters
Mean	39,486	40,974
Variance	485,382	946,287
Skewness (Pearson)	0,652	2,675
Kurtosis (Pearson)	0,000	14,959

Comparing the test results of the Erlang (Table 6) and Log-Normal (Table 5) distribution fittings, it seems like both distributions can be considered to be suitable for a representation of the container creation process, but the Erlang distributions shows some better test results regarding the Chi-square test (observed: 25,1 VS 31,5 by critical: 32,7). Continuing with a visual comparison, the main difference which could be mentioned is that the Log-normal distribution will reduce the risk of the occurrence of extreme small values compared to the Erlang distribution. Because of this observation, it is chosen to use the Log-normal distribution to define the number of containers loaded onto a barge during its creation.

Table 7 container barge creation input parameters per weekday

weekDay	muRot	sigRot	muAnt	sigAnt
1	40	20		
2	36	19		
3			42	25
4	40	20		
5				
6	32	22	36	18
0	52	28		

As next step, after defining a global distribution for all barge loading processes, the input parameters are specified for each weekday, and differ therefore for each created barge type, since the barge type is based on the creation weekday. Table 10 shows the input parameters for different weekdays (1 equals Monday) and barge types ("Rot" = "Rotterdam; "Ant" = Antwerp").

As mentioned earlier in this section, terminals do have different sizes and therefore, a different number of containers needs to be created for each terminal. Since the distributions are based on data of the largest terminal of the network, the number of created containers is reduced by a calculated factor for other terminals, depending on the relative size of these terminals to the largest one. It is decided to use the truck capacities of the terminals to define their relative size. Based on these parameters, the largest terminal (terminal 3+4) has a capacity for 250 trucks, terminal 2 a capacity of 200 trucks, and terminal 1 a capacity of 130 trucks. Thus the relative sizes are then 1 for terminal 3+4, 0,8 for terminal 2 and 0,52 for terminal 3. During validation of the model it has shown that these parameters are too large, leading to deviations from real values of the terminal and to unrealistic long barge queues within the simulation, and are therefore reduced to values of 0,9 (terminal 3+4), 0,6 (terminal 2) and 0,4 (terminal 1). An example for a container creation for barges on a Monday: assuming that the container creation reference for barges on a Monday is 40 containers, then 0,9*40=36 containers with destination terminal 3 are created, 0,6*40=24 containers for terminal 2 and 0,4*40=16 for terminal 1.

5.3.4.2 Parameters container creation: train

In contrast to barges, trains do have a capacity limit, and based on the observations at the terminal, trains are forced to be loaded to maximum capacity if possible, since train voyages are paid per train and not per container. As already described in Section 5.3.2, there exist two types of trains. Large ones serving terminals 2 and 3, and small ones serving either terminal 2 or terminal 3. The small trains have a capacity of 24 containers and are always fully loaded with containers for the only destination terminal of the voyage. For the multi-terminal train, it was analyzed how many containers reach the last terminal, and based on the maximum capacity, the missing containers are then assumed to be unloaded at the first terminal. The frequency diagram, showing the number of containers unloaded per train at the last terminal, can be seen in Figure 9.

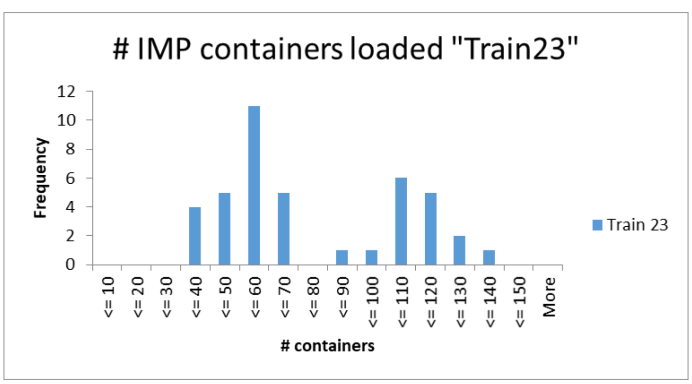

Figure 6 histogram # import containers loaded for "Train23"

Looking at the frequency diagram, it seems like some values lie far above the capacity limit of 99 containers. It is assumed that for the model, only the values below the capacity limit are relevant. To describe the number of containers to load on a train, no distribution is fitted this time, since the graph seems not to be continuous enough, but empirical distributions are used to decide about the size of the load. For this purpose, the four bins of the histogram (31-40; 41-50: 51-60; 61-70) are linked to a cumulative frequency (in 16% of the cases less than 41 containers are loaded, in 36 % of the cases less than 51 containers, …) and a bin is selected on the output of a uniform distribution for values from 1-100. After selecting a bin, another uniform value within the limits of the bin is chosen to simulate some variation in container selection (e.g. the first output is 30, so bin 41-50 is selected, the second uniform output is 44, so 44 containers are loaded for the last terminal). After the number to be loaded containers is defined for one terminal, the number of containers to be loaded for the other terminal is simply calculated by subtracting the selected amount from the maximum capacity of the train. This can be done because trains are always loaded to full capacity, as already mentioned in the beginning of this subsection, and trains do not visit more than 2 terminals during each voyage.

During validation of the model, it seems like working with full capacity trains leads to unrealistic long barge queues, due to the situation that cranes are not able to handle all containers quick enough. Additionally, trains are, other than barges, not exclusively handled by cranes, but also by reach-stackers, which are not modelled here due to complexity reasons. Therefore, the final bins to select the load for a train are decreased by an amount of 20 containers, and the maximum capacity of the multi-terminal train is decreased by 30%. The decrease of 30% is linked to a decrease in number of arriving trucks by 30%, which is needed to adjust the export load levels of barges (for model validity reasons).

5.3.4.3 Parameters container creation: gate

The creation of containers at terminal gates is divided into two phases: Firstly, for each hour, a defined number of containers enter the system, arriving in intervals based on a fitted distribution; secondly, containers are assigned to barge voyages based on pre-barge voyage container dwell time distributions, which is part of the idea behind the approach of Sideris et. al. (Sideris, Boilé, & Spasovic, 2014) to determine the total workload at a terminal.

Starting with the number of expected truck arrivals per hour and day, the terminal data of the container gate-in registrations are filtered based on the containers that are registered within the crane job history. It is important that only containers that are processed by cranes, and not by reach stackers, are selected, since reach stackers are not modelled and the cranes would not be able to handle these extra containers. As next step, the container arrivals are summarized and averaged per weekday and hour of day, resulting in the following Table (Table 12):

Table 8 Average container gate-in arrivals for cranes per hour and weekday

hour	mon	tue	wed	thu	fri	sat	sun	average (mon-fri)
0	0	2	2	2	2	2	0	2
1	0	1	2	2	1	2	0	1
2	0	1	1	1	1	1	0	1
3	0	1	1	2	2	1	0	1
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	5	5	5	5	5	1	0	5
7	3	3	3	3	5	1	0	4
8	6	5	6	5	7	1	0	6
9	11	9	10	12	12	1	0	11
10	13	10	11	13	13	0	0	12
11	11	8	11	11	12	0	0	10
12	10	8	10	10	10	0	0	9
13	9	8	10	10	10	0	0	10
14	12	10	11	12	12	0	0	11
15	12	9	10	11	11	0	0	11
16	9	7	7	8	8	0	0	8
17	6	4	5	5	5	0	0	5
18	3	2	2	3	2	0	0	2
19	4	3	4	4	4	0	0	4
20	3	3	3	4	3	0	0	3
21	2	2	2	2	2	0	0	2
22	1	2	2	1	2	0	0	1
23	2	2	2	2	2	0	0	2

Analyzing the Table, it seems like the arrivals per hour for Monday till Friday are comparable. Therefore, a simplification based on the average values per hour of these days will be used as input data. No distribution can be used here to add variations in container arrivals, since the trigger object within the model, which changes the values per hour during the simulation, cannot handle variations in the number of objects to create.

After the number of containers to create were identified, the inter-arrival times of the containers were another important parameter to define, since containers arrive more frequently in the morning or afternoon than they do in the night. For this purpose, the container gate-in registration data is again used to identify the times between the registrations of containers. A distribution is then tried to be fitted to the observed data of inter arrival times. The data of peak hours resembles a log-normal distribution, but with large peak at the mean, which made it hard to find a well-fitting, statistically significant distribution (compare figures 10+11 & tables 9+10). Since the log-normal distribution provides less extreme values near zero, compared to distributions with similar shapes, the log-normal distribution is chosen to be used as input parameter for all hours. An overview of all input parameters can be seen in Table 15.

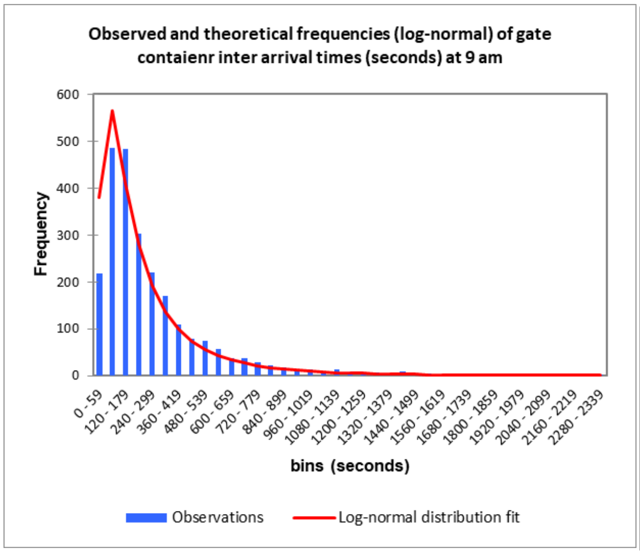

Figure 8 container inter arrival time Log-normal distribution fitting hour 9

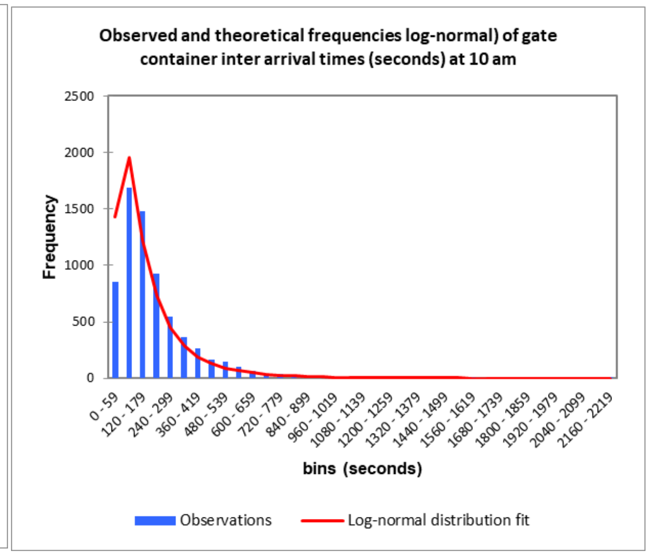

Figure 7 container inter arrival time Log-normal distribution fitting hour 10

Table 10 container inter arrival time Log-normal input parameters hour 9

Chi-square (Observed value)	158,504
Chi-square (Critical value)	50,998
DF	36
p-value	< 0,0001
alpha	0,05

Statistic	Data	Parameters
Mean	245,089	246,650
Variance	68726,238	89735,504
Skewness (Pearson)	2,599	5,435
Kurtosis (Pearson)	9,397	80,226

Table 9 container inter arrival time Log-normal input parameters hour 10

Chi-square (Observed value)	526,251
Chi-square (Critical value)	48,602
DF	34
p-value	< 0,0001
alpha	0,05

Statistic	Data	Parameters
Mean	173,930	174,219
Variance	28067,229	33580,944
Skewness (Pearson)	2,543	4,319
Kurtosis (Pearson)	10,755	45,687

Table 11 inter arrival times (seconds) log-normal input parameter hourly overview

time period	Mean	Variance	sigma
02:00-05:00	1534	9858155	3140
06:00	524	871795	934
07:00-08:00	522	690213	831
09:00	247	89736	300
10:00-11:00	174	33581	183
12:00-15:00	191	44660	211
16:00-17:00	278	127066	356
18:00-19:00	622	1114814	1056
20:00	955	3702671	1924
21:00-01:00	1155	4314068	2077

Containers are now created at gates, but still need to be assigned to a voyage. This will be done based on pre-voyage container dwell times. Containers arrive distributed over some days prior to the arrival of the barge. Since barges arrive at multiple days, arriving containers can be intended for each of these barges, but with a higher chance for an earlier arrival.

First, one general arrival pattern of containers is determined for all barge voyages, based on container data filtered from gate in activities and barge loading jobs of cranes. The result can be observed in Figure 12.

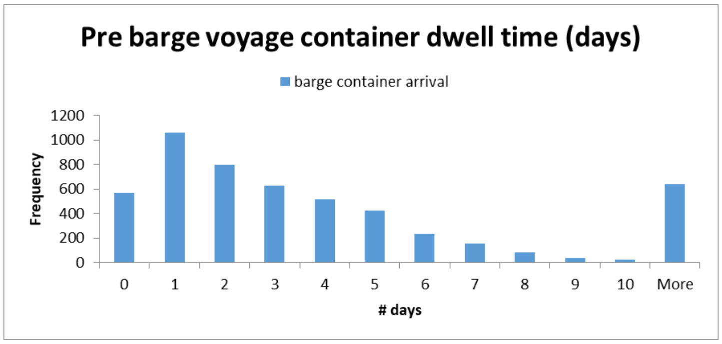

Figure 9 histogram pre-barge voyage container dwell time (in days)

It seems like most of the containers arrive within one week prior to the barge voyage. It needs to be mentioned that large amount of data had a negative arrival time, or much larger arrival times. It is assumed that the identification number of containers is not unique, or not properly tracked, and are therefore used or detected more than one time during the analysis and wrongly assigned to the voyage. For this model, only arrivals up to six days are used, since Table 12 showed that few container arrivals are expected for Sundays, and because barge voyages have a period of one week. During observations, employees of the terminal mentioned that most of the containers arrive within three days prior to the voyage.

To determine, which percentage of the containers arriving at a selected day are assigned to which voyage, a matrix is created that includes the amount of containers arriving per day for a given voyage, assuming 100 containers to arrive in total during the week for each voyage. The Matrix looks like in Table 12. The fraction of containers assigned to a given voyage per day can then easily be calculated and is shown in Table 13.

Table 12 conceptual container arrivals per day of week and barge voyage

Barge/Day	1	2	3	4	5	6	7
Rot1	13		18	12	14	18	24
Rot2	24	13		18	12	14	18
Ant3	18	24	13		18	12	14
Rot4	14	18	24	13		18	12
Rot6	18	12	14	18	24	13	
Ant6	18	12	14	18	24	13	
Ant7		18	12	14	18	24	13

Table 13 matrix with fractions of containers to assign per day to a given voyage

Barge/Day	1	2	3	4	5	6	7
Rot1	12%	0%	19%	13%	13%	16%	30%
Rot2	23%	13%	0%	19%	11%	13%	22%
Ant3	17%	25%	14%	0%	16%	11%	17%
Rot4	13%	19%	25%	14%	0%	16%	15%
Rot6	17%	12%	15%	19%	22%	12%	0%
Ant6	17%	12%	15%	19%	22%	12%	0%
Rot7	0%	19%	13%	15%	16%	21%	16%

An arriving container at the gate of a terminal can now be assigned to a voyage based on these fractions, in cumulative form, using a uniform selection for values from 1 to 100.

Additionally, observations have shown that trains are mainly loaded with rescheduled barge containers. Therefore, 15% of the incoming containers are directly assigned to trains. The value of 15% is chosen based on validity and system capacity reasons.

5.3.4.4 Container parameters: yard dwell time

Containers face not only dwell times prior to a voyage, but also wait some time in the yard before a truck distribution takes place. The yard dwell times, in days, are calculated like the pre-voyage dwell times in Section 5.3.4.3, with the difference that there is no need to differentiate between voyages. The frequencies of observed yard dwell times, and hours during which containers leave the yard frequently are shown in figures 13 and 14.

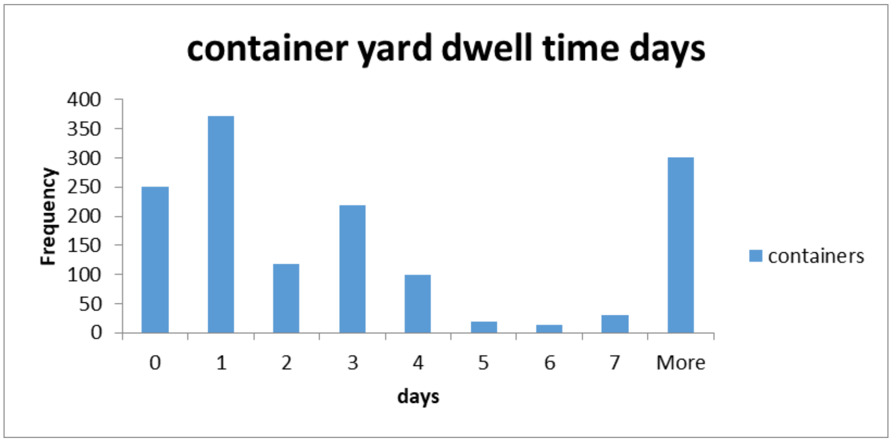

Figure 11 histogram container yard dwell time days

Figure 13 shows that most of the containers leave the yard within four days after they are unloaded from a barge. Again, a uniform distribution is used to assign a dwell time to a container that enters the yard.

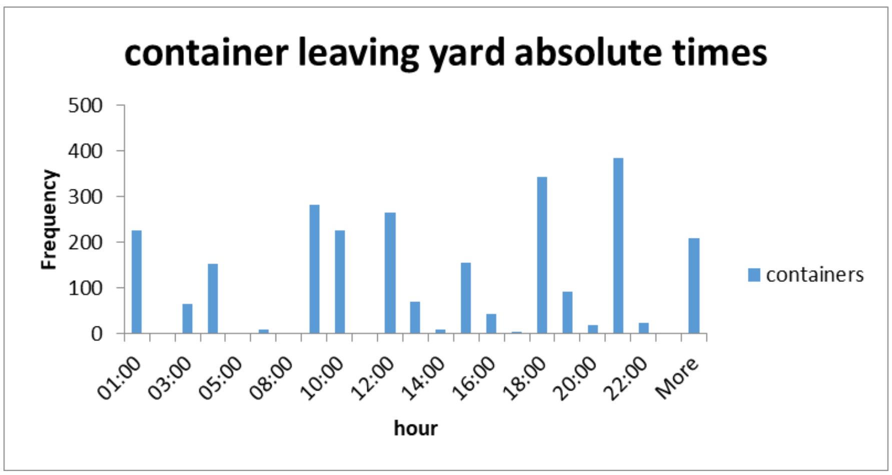

Figure 10 histogram container leaving yard absolute times

Figure 14 shows that containers leave the terminal in a relatively unstable hourly pattern. It is decided that the day will be separated into three segments for containers to leave the terminal. The first section between 9 am and 12 am, the second one between 1 pm and 5 pm, and the last one from 6 pm and 9 pm. The departure hour and minute is then also selected using a uniform distribution.

5.3.5 Crane operator shift parameters

The shift system of crane operators for the terminal is relatively simple. There are three shifts per day for each day of a week. The early shift is from 6 am until 2 pm, the late one from 2 pm until 10 pm, and the last one is the night shift from 10 pm until 6 am. For shifts on Sundays and night shifts, only one crane operator can be requested. For all other shifts, there exists an option to request two crane operators, based on the capacity of the terminal. The amount of crane operators to be requested is defined a day before by a forecast method.

5.4 Forecast scenarios implementation

The experimental factor of this model is the forecast method for ETAs of barges, with three scenarios already introduced in Section 4.6. For all forecast scenarios, it is assumed that a GPS tracking system ("i&Land") is used, making the positions of all barges available at every time. Furthermore, all forecasts are generated during the simulation with information available at 2 pm every day, based on the results of the real observation at the terminal. The process of the forecast calculations during the simulation looks like follows and are repeated for every barge within the system:

1) The position of a barge within the system is requested at 2 pm every day. The position, the expected barge travel speed (fixed per travel direction) and the distance to the next planned terminal are used to calculate the inter-terminal travel time to this terminal for this barge.
2) For the next planned terminal it is checked whether the barge is expected to arrive within an already planned shift (thus cranes are already planned), or not.
    a. If arrival shift is already planned, the number of cranes planned for the arrival shift will be used for terminal throughput time calculations
    b. If arrival shift is not already planned, two cranes are planned for this shift if possible and used for terminal throughput time calculations.
3) The expected throughput time at the next terminal is calculated as follows
    a. The amount of loaded containers for the next terminal of the selected barge are added to the containers waiting at this terminal for the barge, plus the expected number of missing containers for this voyage.
    b. The resulting total expected number of containers for this barge is multiplied with the average processing time of cranes, with respect to the amount of cranes expected to be available for processing.
    c. It is checked whether the barge is expected to be processed within more than one shift. In this case, step 2) is executed again for the follow-up shift after the arrival shift.
4) 15 minutes dwell time are added to the throughput time, since barges will wait at a terminal for some minutes after the last container intended for the barge is picked up by a crane. This ensures that all containers are loaded or unloaded from the barge correctly.
5) All steps are repeated for all residual terminals of a barge voyage.

The scheme above holds for the standard forecast method used in reality at the terminals, excluding train and truck containers which needs to be processed by the cranes simultaneously to the barges. For the two experimental forecast scenarios (see Section 4.6) additional steps are added to stage 3, the calculation of the throughput time:

> 3) a.2 The number of expected container arrivals and departures by truck at the next terminal for the shifts the barge is expected to be processed at this terminal are added to the total expected number of containers used for the terminal throughput time calculations.
>
> 3) a.3 It is checked whether another barge is expected to be processed within the same shift. The expected number of import and export containers for this additional barge are then added to the total expected number of containers used for the terminal throughput time calculations.

Furthermore, only for the second scenario, where train processing is included in ETA calculations of barges, the following step is added to the scheme:

3.a.4 It is checked whether another train is expected to be processed within the same shift. The expected number of import and export containers for this train are then added to the total expected number of containers used for the terminal throughput time calculations.

i. If no train is detected within the system, historic data is checked for arrivals of trains that could occur during the barge arrival shift. In that case, the moving average of the import and export containers handled for this sort of train during the last three weeks is used to estimate the amount of containers to be handled with the upcoming train arrival.

5.5 Validity of the model

The validity of the model will be tested by comparing the distributions of the number of import and export containers of a barge, and the throughput times of barges at terminal 3, representing the terminal which was observed in reality, with the real data. Before these validity tests are executed, a warm-up period for the simulation needs to be defined, since the simulation will start with a completely empty network, which does not fit reality. Only values that lie outside the warm-up period, when the system reached a steady state, will be used for validity checks and further analysis. The steady state for this system will be defined via the barge total network throughput time. The steady state will be reached when the average throughput time stays relatively stable during the simulation. The validity of the model can only be tested based on the assumption that the system runs stable with all predefined parameters included.

5.5.1 Calculation of the warm-up period

To define the warm-up period, a heuristic method known as the 'marginal standard error rule' (MSER) is used. Following Robinson (Robinson, 2014), this method is recommended by Pasupathy and Schmeiser (2010), and Nelson (2013), since its performance on estimating the warm-up period is consistently well, with the benefit that no assumptions or parameters of complex calculations are required. The aim of the MSER is described by Robinson, with reference to White (1997), as "to minimize the width of the confidence interval about the mean of the simulation output data following deletion of the initial transient data." This means that early observations that are too far away from the mean of all observations are removed. The warm-up period should be chosen for a point in the simulation which minimizes the MSER value (Robinson, 2014).

In the case of this simulation, the MSER is applied to the weekly average total network throughput time of barges, since the simulation handles a periodical of one week. The related graph is shown in Figure 15.

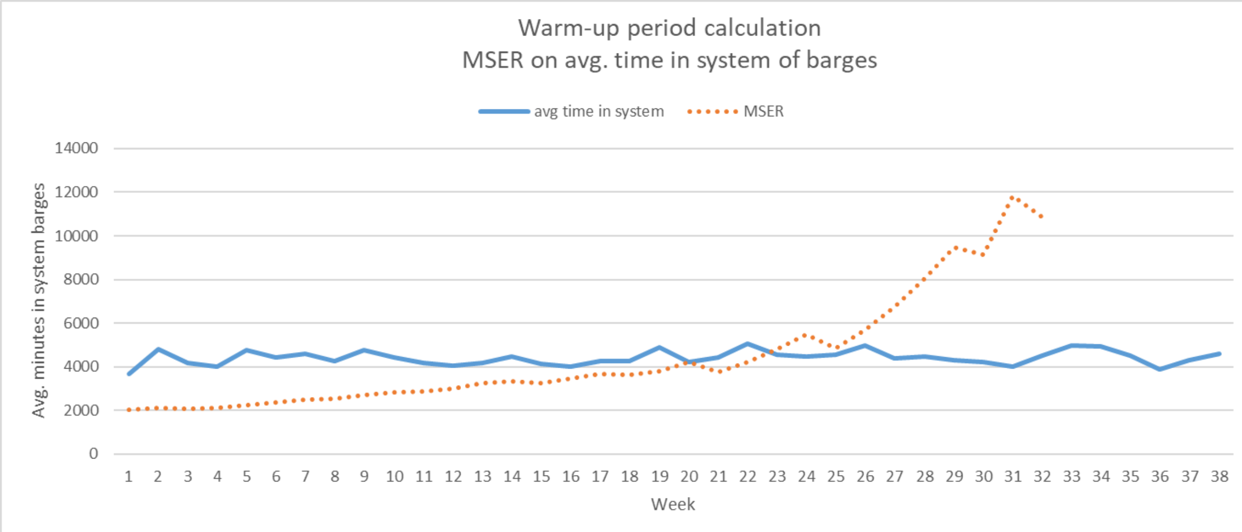

Figure 12 warm-up period calculation (MSER on average time in system per week)

The minimum MSER value observed is in week 1 with a value of 2042. Week 1 is not suitable for the selection of a warm-up period, since the system is still relatively empty after such a short time. There is another minimum in week three with a MSER value of 2091. Therefore, it is chosen to apply a warm-up period of three weeks.

5.5.2 Validity test: frequency number of barge import and export containers

The first validity test is focused on the observed frequency of number of barge import and export containers, since barges are fully processed by cranes and the number of barge containers have a main impact on the barge throughput times at terminals and for the whole network. Figure 16 shows the histogram of real frequencies, compared to the simulation output with different parameters. “Sim1” stands for a simulation where the initial derived distributions are used.

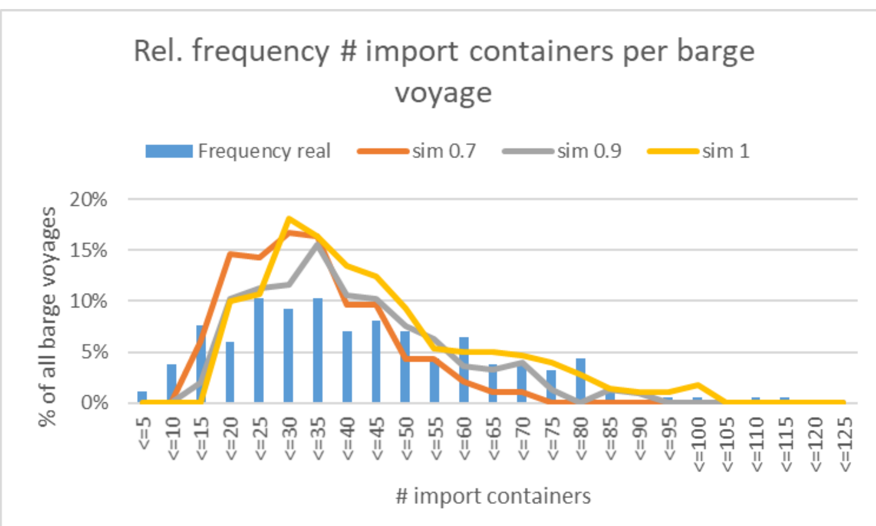

Figure 13 validity test rel. freq. of number of barge import containers

It could be observed that simulation runs with the original derived distributions for assigning import containers to barges (sim1), results in more observations around the mode and for larger loads. After experimenting with some parameters to reduce the number of containers assigned initially to barges, for example reducing the total amount by 10% by applying a factor of 0,9 (sim 0.9), it is decided to reduce the amount of import containers for all barges by 10% (sim0.9).

Looking next at the frequency of number of export containers (Figure 17), it can be seen that the real frequency is of a more uniform nature, where the observations of the simulation runs have the character of a normal-distribution. Since the assignment of container to barge voyages is based on dwell times, like described in Section 5.3.4.3, it is complex to influence the shape of the distributions, representing the frequency of number of export containers, directly. Reasons for the differences between observed and simulated values could be the extreme noise of the input data to calculate pre-voyage dwell times, or the lack of differentiation between different voyages, due to complexity reasons. It is decided to try to shift the mode of the simulation values to the left, thus reduce the value, by reducing the total number of container arrivals at terminals by 30% (factor 0,7; sim0.7). No further action is done, since the throughput times of barges at the terminal seem to have a good fit, which is assumed to be the most important factor of validity (see following section).

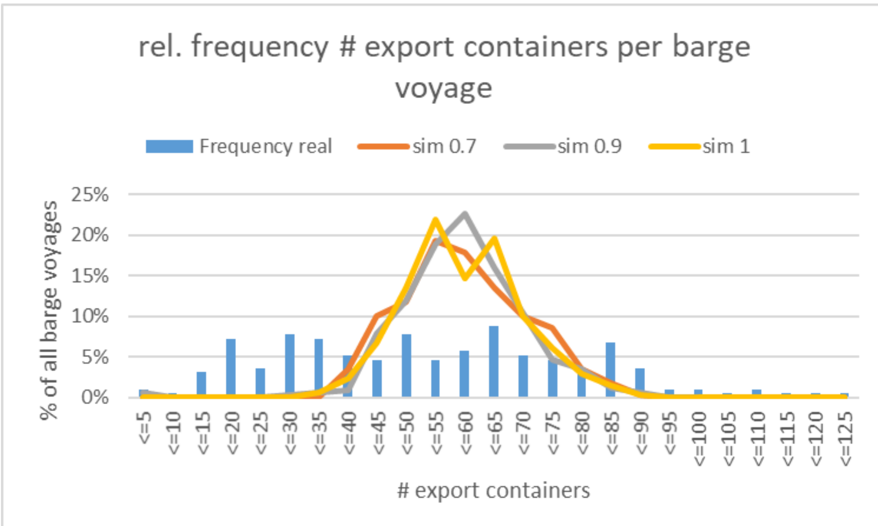

Figure 14 validity test rel. freq. of number of barge export containers

5.5.3 Validity test: terminal throughput times of barges

With the adjusted parameters of Section 5.5.2, the throughput times of barges in the simulation fit the values of real observations in an acceptable way (Figure 18). It can be derived that the validity of the model is sufficiently high, also having in mind the reduced complexity of the model compared to the real complexity of the hinterland network, to gain valid results from analysis of forecast scenarios and the test of the hypotheses.

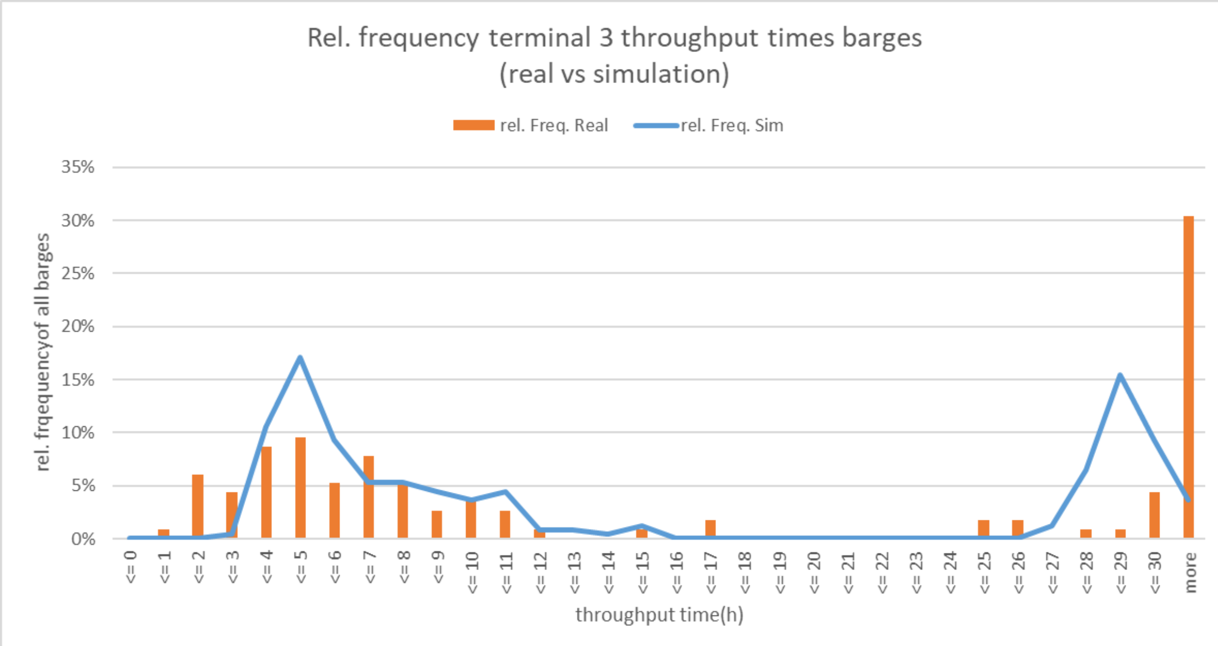

Figure 15 rel. frequency terminal 3 throughput times barges

5.6 Analysis of forecast scenarios (“vehicle only” & “all TEUs”)

After the validity of the model was tested, it can be continued with the comparison of results from the different forecast methods described in Section 4.6 and Section 5.4. The forecast methods are compared first based on their overall forecast performance, by showing the frequency of barge arrival time forecast errors in minutes (Figure 19). Each analysis is made for terminal 3 of the model, which represents the real observed terminal (CTS).

By examining Figure 19 it can be seen on the one hand that the standard method (“vehicle only”), the forecast based only on barge containers, systematically underestimates the arrival times of barges, therefore, barges arrive later than forecasted. On the other hand, the forecast method, which takes all potential container movements into account (“All TEUs”), is systematically overestimating the arrival times of barges. It is therefore assumed, that the forecast method overestimates the number of containers for one or more of the three main forecast categories: the train containers, the truck import containers, and/or the truck export containers.

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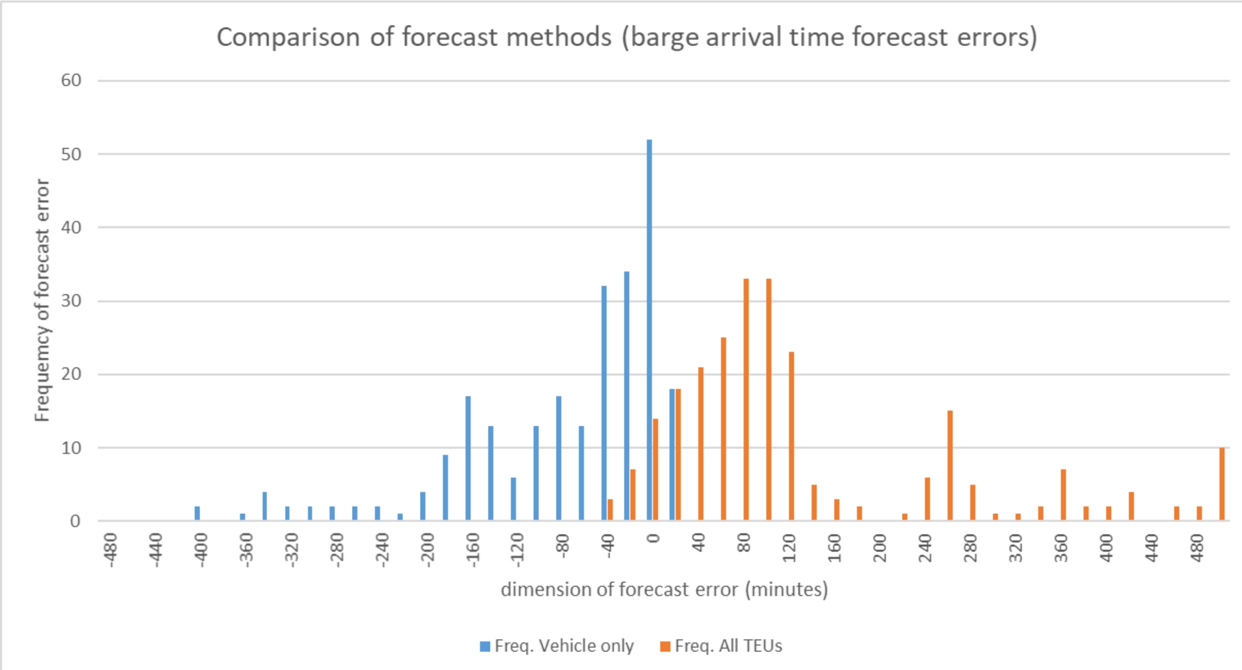

Figure 16 comparison of forecast methods Terminal 3 (barge arrival forecast errors)

Figure 20 shows the frequency of forecast errors for the number of container movements during a barge processing at a terminal, extracted from a simulation run with all containers used for forecasting.

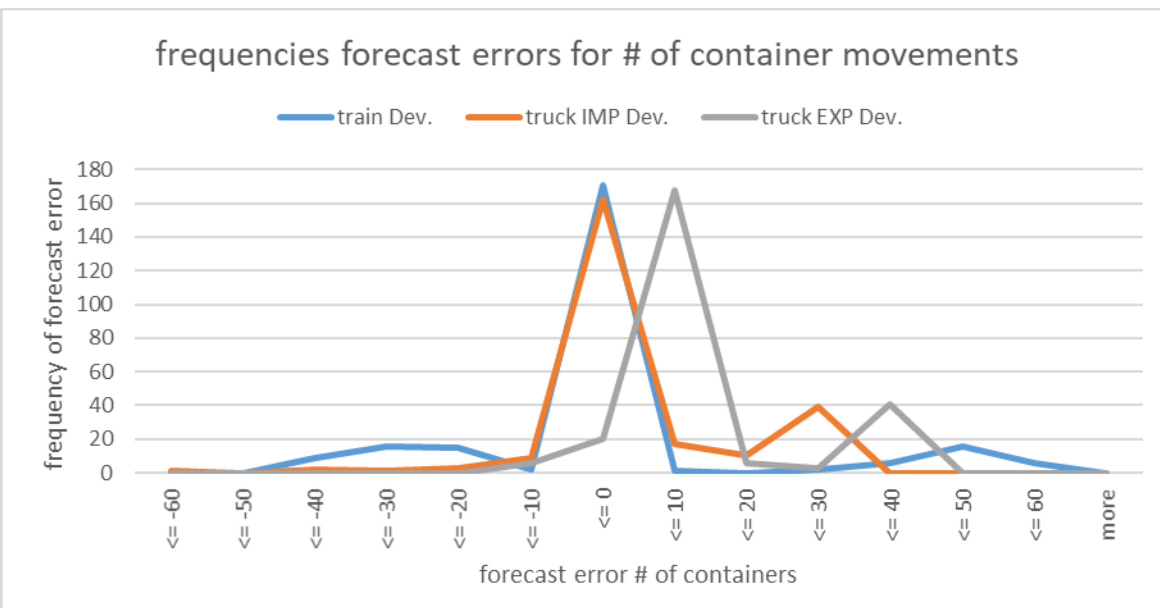

Figure 17 frequencies forecast errors for # of container movements Terminal 3

The first observation of Figure 20 is, that the estimations of the number of truck import containers ("truck IMP Dev.") during a barge processing, seems to fit relatively good, besides a little peak of overestimations. This could be explained for the cases where ships are intended to arrive in a late shift, but their real arrival

was in a night shift with a lower frequency of container arrivals.
Looking at the forecast errors for the number of train containers (“train Dev.”), they seem to provide a good fit at the first glance, since most of the observations seem to fit exactly, with relatively few extreme over- and underestimates. But at the second glance it becomes clear that the observations with a deviation around zero are observations where no train was expected to arrive. This changes the situation to the fact that train forecasts do not seem to fit at all by using the selected forecast method. Trains seem to arrive systematically when they are not expected. This could explain the extreme overestimations which can be seen in Figure 19.
Lastly, observing the forecast of the number of truck export containers (“truck EXP Dev.”), it seems like their amount is systematically overestimated. The reason behind this can only be a wrongly created Table which contains the average number of truck export container movements per shift.

Graphs for terminal 2 can be found in Appendix 1. For terminal 2, two different arrival times of barges are tracked, one for the import and another for the export stop. Since the import stop takes place relatively early in the network, no large deviations are assumed and are also not visible in the graph, for none of the forecast methods. The export graph shows even larger spreads, but a comparable pattern to the graph of terminal 3 observed in this section above.

In summary, it is decided, based on the given insights, that another forecast method needs to be applied. The forecast method will not handle train forecasts at all and will work with an updated truck export list.

5.6.1 Analysis of forecast scenarios: adjusted forecast (“gate barge”)

The adjusted forecast method includes the expected number of containers intended for the barge only, and the expected number of containers representing truck imports and exports as container input. A comparison of the standard and the adjusted forecast method in Figure 21 shows that they are relatively similar, but the adjusted forecast has now some less underestimations and some more overestimations. The overestimations are limited to a deviation of two hours, so a group of barges arrives 2 hours earlier than predicted.

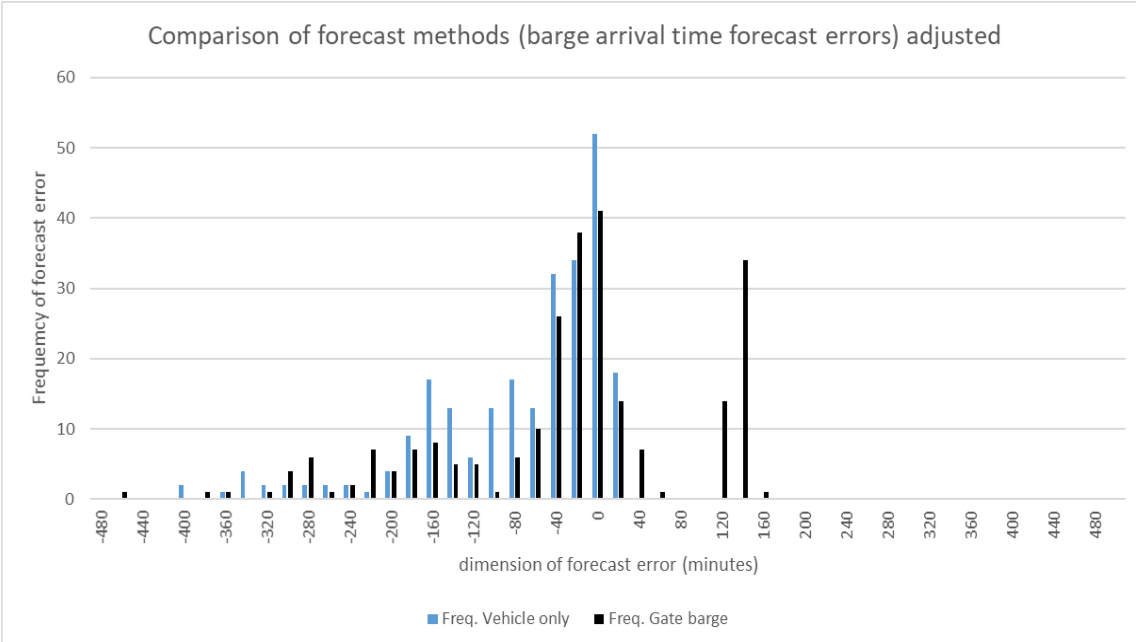

Figure 18 comparison of forecast methods (barge arrival forecast errors) adjusted

The underestimations are also visible in Figure 22, showing that the forecast error for the number of truck export events are now shifted to a more underestimating scheme.

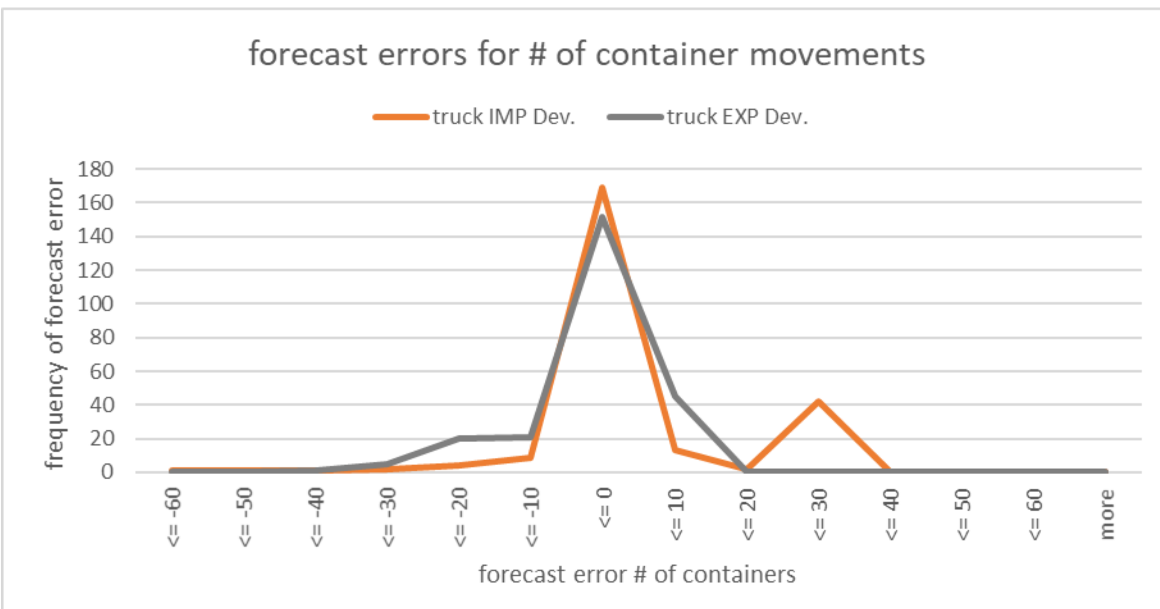

Figure 19 forecast errors for number of container movements adjusted

To improve the results further, some deeper analysis of the parameters for the other terminal could unlock some more options for adjustments. Also the implementation of a learning algorithm, which adjusts the over- and underestimations automatically, could lead to further improvement. Since the input data for arriving and departing trucks was relatively noisy, the input parameters for gate events were relatively fixed, and due to project time restrictions, it was decided to stop the adjustment of the forecasts methods at this point and to continue with a statistical evaluation of the given results.

5.6.2 Forecast scenarios analysis: forecast error

To evaluate the forecast methods, the standard one with vehicles only, the one with all containers included, and the one including gate and barge activities, three different measures of the forecast error are executed. The first one is the Mean Squared Error (MSE) which is related to the variance of the forecast error (Chopra & Meindl, 2013). The MSE penalizes large errors much more significantly than small errors, which suites the requirements of a barge arrival forecast for a terminal. Larger deviations may lead to an arrival in another shift and can have a huge impact on throughput times.

The second measure is the Mean Absolute Deviation (MAD), which is the average of the absolute deviation over all periods. The last measure is the bias, indicating whether the errors are randomly distributed around 0. Additionally, the Tracking Signal (TS) is calculated for all observations to indicate an over- or underforecasting. Table 18 shows the forecast error measurements per forecast method.

Table 14 table overview on forecast error measurements (terminal 3)

Forecast method	MSE	MAD	bias
vehicle only	15151	85	-20574
all TEUs	36853	133	31759
gate barge	15932	92	-9431

By analyzing Table 14 it is obvious that the forecast handling all containers ("all TEUs") is performing the worst. The MSE is twice as high as observed by other forecast methods, due to extreme overforecasting, as indicated by the TS and the bias. The other two forecasts seem to have a comparable performance. The MSE and MAD are nearly the same, and both do underforecast extremely, but the bias is much nearer to zero for the forecast handling barge and gate activities. This can be explained by the group of overforecasts with a deviation of 2 hours. This adds a more random component to the forecast results, and the MSE punishes this overforecasts.

The tables with forecast error analysis for terminal 2 can be found in Appendix 1. The values for the import are relatively similar for all forecast methods, but the export results show that the gate-barge forecast method shows a slightly better statistical performance than the standard forecast. Therefore, it seems that the gate-barge forecast method performs better as more variables, in this case more terminals, are faced.

In summary, it could not be concluded that an adjusted forecast method performs better than the standard method which is used at the moment, based on the observed forecast error measurements. But it needs to be considered, that the gate and barge forecast method shows a less random deviation, due to some overforecasts within a range of two hours. This means that barges arrived two hours earlier than predicted, but were still processed within their intended arrival shift, since nearly all barges need more than two hours to pass a terminal (see Figure 18). It seems also that only a special group of barges is overestimated, and this group could be identified and corrected. In general, the underforecasts can also be divided in multiple groups (Figure 21), where it can be assumed that these groups could also be identified and corrected.

A final statement regarding the acceptability of the hypotheses can be derived only after executing a *t*-test for the vehicle only and gate-barge forecast methods (see following section 5.6.3).

5.6.3 Forecast scenarios analysis: t-test for hypothesis 1

To derive a final statement whether hypothesis 1

"Including a prediction of all crane operations at terminals, within an intermodal hinterland network, in ETA calculations of barges decreases the forecast error for barge arrival times significantly."

can be accepted or not, a t-test is performed to test whether the mean of the absolute forecast errors of the forecast method "gate-barge" are significantly different from the mean of the absolute forecast errors of the standard forecast method ("vehicle only"). Results for terminal 3 and the export part of terminal 2 are shown in tables 28 and 29 respectively.

Table 28 t-test terminal 3 vehicle only vs barge gate forecast method

t-Test: Paired Two Sample for Means	*At vehicle only*	*At barge gate adj*
Mean	84,75	90,86
Variance	7939,63	7373,55
Observations	246,00	246,00
Pearson Correlation	0,20	
Hypothesized Mean Difference	0,00	
df	245,00	
t Stat	-0,86	
P(T<=t) one-tail	0,19	
t Critical one-tail	1,65	
P(T<=t) two-tail	0,39	
t Critical two-tail	1,97	

Table 29 t-test terminal 2 EXP vehicle only vs barge gate forecast method

t-Test: Paired Two Sample for Means	*At vehicle only EXP*	*At barge gate EXP*
Mean	164,46	150,17
Variance	34558,69	22493,88
Observations	344,00	344,00
Pearson Correlation	0,93	
Hypothesized Mean Difference	0,00	
df	343,00	
t Stat	3,68	
P(T<=t) one-tail	0,00013	
t Critical one-tail	1,65	
P(T<=t) two-tail	0,00027	
t Critical two-tail	1,97	

Since only the forecast method changed, but no other parameters within the two simulation runs, the barge samples are assumed to be directly comparable, and therefore the "Paired Two Sample for Means" test has been chosen, with an alpha of 0,05 and no change hypothesized. Only the one-tail parameters are observed, since only a decrease is of interest for hypotheses 1.

For terminal 3, the resulting t value is smaller than the critical value of t (-0,86 < 1,65), and the P-value lies above the chosen critical alpha-value (0,19 > 0,05). Therefore, it cannot be assumed that the "gate barge" forecast method decreases the forecast error for barge arrival times significantly at terminal 3.

For terminal 2, the resulting t value is larger than the critical value of t (3,68 > 1,65), and a statistically significant difference could be found (p < 0,00). Therefore, taking also the smaller mean and variance of the "gate barge" forecast method compared to the standard method into account, it could be assumed that the "gate barge" forecast method decreases the forecast error for barge arrival times significantly at the export part of terminal 2.

Table 28 terminal 2 (export) MSE deviations compared to "vehicle only" method

Forecast method	MSE %	MAD %	bias %
vehicle only	0%	0%	0%
all TEUs	29%	21%	-12%
gate barge	-27%	-9%	-40%

Table 29 terminal 3 MSE deviations compared to "vehicle only" method"

Forecast method	MSE %	MAD %	bias %
vehicle only	0%	0%	0%
all TEUs	143%	56%	54%
gate barge	5%	8%	-54%

By comparing terminal 2 (export arrivals) and terminal 3 based on the effects of the forecast methods on the MSE (Tables 18 & 14), it showed that the MSE value of 44978 for terminal 2 (export arrivals) with the "gate barge" forecast method is still higher than for terminal 3 with a value of 15932 , but the MSE for arrivals at terminal 2 is reduced by 27% through the "gate barge" forecast method, while it even increased

slightly at terminal 3 (Tables 28 & 29).
Hypotheses1 could therefore be partly accepted for some terminals at the end of the terminal network.

5.6.4 Forecast scenarios analysis: entities throughput times (hypothesis 2)

forecast method	avg. Barge system throughput time (hours
vehicle only	74
all TEU	65
gate barge	65

Table 15 avg. barge system throughput time in hours per forecast method

Since at least one forecast method performed significantly better than the standard method for some terminals, other parameters are further analyzed, like the throughput times of entities as part of hypothesis 2, to detect whether over- or underforecasting has an effect on these parameters.
Looking first on the average total system throughput times for barges (Table 15), it seems like all alternative forecast methods decrease the average system throughput times of barges by nine hours. The reason for this decrease needs to be detected by observing additional parameters.

One cause of this decrease in the overall barge throughput time could be the assignment of cranes to the right barge arrival shifts at terminal 2 or 3, which are the terminals at which theoretically two cranes are available for barge processing. Table 16 shows an overview of barge arrivals and crane matches, with the number of barges which arrived during an early of late shift, and the number of operating cranes available for this shift.

Table 16 overview planning match: barge arrival and crane planning

vehicle only

Crane fit T3	early	late	% early	% late
2 cranes	48	24	96%	100%
1 crane	2	0	4%	0%

vehicle only

Crane fit T2	early	late	% early	% late
2 cranes	0	0	0%	0%
1 crane	214	175	100%	100%

all TEU

Crane fit T3	early	late	% early	% late
2 cranes	19	11	38%	46%
1 crane	31	13	62%	54%

all TEU

Crane fit T2	early	late	% early	% late
2 cranes	98	73	46%	42%
1 crane	116	102	54%	58%

gate barge

Crane fit T3	early	late	% early	% late
2 cranes	48	11	96%	46%
1 crane	2	13	4%	54%

gate barge

Crane fit T2	early	late	% early	% late
2 cranes	99	73	46%	42%
1 crane	115	102	54%	58%

The overview shows surprising results regarding the assignment of cranes. It seems like it makes no difference, regarding crane assignment performance, whether a non-standard forecast method is used or not. About 40% of all barges are processed by two cranes directly after arrival, at each terminal, with an exception for an early shift prediction quote of 96% for the gate-barge forecast method. In general, a rate of 40% regarding the right assignment of cranes cannot be described as a satisfying quote, also compared to the real value for terminal 3 with a quote of 74% for a barge processing with two cranes .But looking at the standard forecast method ('vehicle only'), the performance gap between terminal 2 and 3 is extreme. The fit for terminal 3 regarding crane assignments is nearly 100%, where the forecasts for terminal 2 are never correct. Comparing the performance of terminal 2 for all forecast methods with the total system throughput times of barges, it seems like the performance of terminal 2 influences the performance of the whole system more extreme than terminal 3 does. The main difference between the terminals is, that barges arrive and depart two times during a voyage, one time for import and the other time for export containers, while they stop only once at terminal 3. Therefore, two forecasts are needed for terminal 2, which increases the chance of a worse terminal performance based on the crane assignments.

In summary, the analysis of the crane assignments shows that compared to the standard forecast method, all other forecast methods reduce the total system throughput times of barges, but the gate-barge forecast method additionally provides the best crane-barge matches for terminals 2 and 3.

The container throughput time is not analyzed separately, on the one hand due to noise in simulation output, and on the other hand because it is assumed that the container throughput times are relatively fixed, since fixed dwell time distributions and no crossdocking operations are applied.

5.6.5 Forecast scenarios analysis: entities waiting times

Another open question after identifying the crane assignment performances is, whether the crane matches only influence the processing time, or also the waiting times of barges prior to processing. Table 17 shows an overview of the percentage of arriving barges which need to wait at a terminal with more than 1 crane.

Table 17 overview % barges waiting and avg. waiting time

vehicle only

Terminal	% IMP barges waiting	% EXP barges waiting
T2	17%	37%
T3	0%	-

vehicle only

Terminal	avg. Barge waiting time IMP (min)	avg. Barge waiting time EXP (min)
T2	137	33
T3	0	-

all TEU

Terminal	% IMP barges waiting	% EXP barges waiting
T2	17%	37%
T3	0%	-

all TEU

Terminal	avg. Barge waiting time IMP (min)	avg. Barge waiting time EXP (min)
T2	137	33
T3	0	-

gate barge

Terminal	% IMP barges waiting	% EXP barges waiting
T2	17%	37%
T3	0%	-

gate barge

Terminal	avg. Barge waiting time IMP (min)	avg. Barge waiting time EXP (min)
T2	137	33
T3	0	-

The overview shows that are neither differences in number of barges waiting, nor difference in the average waiting time.

The truck waiting times cannot be analyzed due to unexpected noise in simulation output. Since trucks are prioritized during crane processing, no large variations in waiting times are assumed for different forecast methods.

6. Summary

The summary of this research is presented in three parts. Starting with answers given to the hypotheses, continuing with answers for research questions from Section 2, end closing with a summary on research limitations and further research suggestions.

6.1 Results of hypotheses tests

The following two hypotheses were intended to be tested with the simulation:

1) Including a prediction of all crane operations at terminals, within an intermodal hinterland network, in ETA calculations of barges decreases the forecast error for barge arrival times significantly.
2) A decreased forecast error for barge arrival times has a significant effect on a decrease in throughput times of transport vehicles and containers at a terminal.

Regarding hypothesis 1), on the one hand, the forecast method that includes all containers, also trains, performed the worst. The reason for this is assumed to be an insufficient train workload forecast. On the other hand, the forecast method that included gate activities performed statistically better only for terminals at the end of the transport network. The forecast errors are still large and the hypotheses can only be partly accepted, since it is not true for all terminals within the network.

Regarding hypothesis 2), there was a measurable decrease in total system throughput times of barges, but not only due to a statistical measurable decrease of barge arrival forecast errors, since it is assumed that underforecasting leads to a better fit of final barge arrival shifts and planned crane operator shifts for terminal 2. Therefore, hypotheses 2 cannot be fully accepted, too.

6.2 Answered research questions

After finishing the analysis of the simulation results, all open research questions can be answered. The sub-questions were defined as follows:

i. Which information shared within the intermodal hinterland transport network is essential for operational planning activities at intermodal hinterland terminals?

This research question is already answered in section 4.2. Main points are:

- Time and modality restrictions of containers, provided by the customers, for container rescheduling tasks.
- Precise ETAs of barges, provided by the barge operator, for crane operator shift planning.
- Load and delete lists, and the stow plan, provided by the barge operator, to create job lists for cranes and reach stackers.
- Time restrictions of containers, provided by customers, as well as ETAs of barges and trains, provided by the barge operator, to assign container disposition orders to trucks.

ii. In which way is the throughput time of entities at intermodal hinterland terminals correlated to the communication performance within the intermodal hinterland transport network?

There was not sufficient data available from the terminal, regarding the ETAs communicated for forecasting purposes, to analyze a correlation between the real communication performance and the throughput time. But the simulation has shown some reductions in total system throughput times for barges of 12%, after adjusting the forecast methods for requesting crane operators. A better communication performance on ETAs, thus the accuracy of communicated arrival times forecasts, could only be statistically verified for a terminal at the end of the network, which led to a better match in arrival shifts and crane operator shifts. The effect was visible for forecast methods which led to more overforecasts.

iii. How could the Information System for an intermodal hinterland terminal be adjusted to further improve the communication performance within the intermodal transport network?

The concept of forecasting with improved terminal throughput times, by using estimations of the total workload expected for cranes, needs an adjustment in the communication structure within the network. The terminals could communicate their expected workload directly with other terminals within the network, to generate throughput times for each stop of a barge step by step, by also adding the automatically communicated information on barge inter-terminal travel times via the new "i&Land" application. This would lead to the situation that terminals stop relying only on information provided by the barge operator, but enabling them to do their own forecasts. Other, interconnected hinterland transport networks could be added, assuming a better forecast performance for all connected terminals, the greater the information network is.

iv. Which effects could these adjustments have on the average throughput time of entities at intermodal hinterland terminals

The effect on the average system throughput times of barges, measured for the small network in the simulation, was a decrease of 12%. For larger networks and further improved forecast methods the effect is expected to become greater. Furthermore, options to increase the number of crossdocking activities were not taken into account for this simulation. It is assumed that an increase in number of crossdocking activities can lead to a significant decrease in terminal throughput times of barges, since a large amount of crane jobs would be erased. An improved forecast method for arrivals of barges could be linked to a more short-term truck disposition planning, with the option to increase the number of crossdocking activities. This could be a subject for further research.

How can the communication within the intermodal hinterland transport network be improved by an Information System (of Yellowstar) to minimize the average throughput time of entities at intermodal hinterland terminals?

The simulation showed that changes in forecast methods for barge arrivals, by adding a communication component between terminals of a hinterland network on their expected workload, can have effects on the total system throughput times of barges. But further research is needed to improve these forecast methods, since the provided forecast methods in this research only showed statistically relevant improvements for some terminals at the end of the network. As also mentioned in the answer to the sub-question iv, it could be valuable to expand further research on linking truck distribution planning to the barge arrival forecasts, to potentially increase the number of crossdocking activities, and therefore decrease also vehicle throughput times at terminals.

6.3 Research limitations and further research

This research faced some limitations, mainly due to restrictions in time and data available. Sufficient data for a simulation of terminal processes was only available for the largest terminal of the network. As a simplification, only two of the four smaller terminals of the real network were simulated based on assumptions made from the data available of the largest terminal. Further expand of this research could include data of other terminals, more terminals, or even more networks, as suggested in section 6.2. In such a case, it would be necessary to check whether the increased complexity adds sufficient value to the results, but results of this research indicated that positive effects of improved forecast methods are larger for terminals positioned later in networks.

Other options for further research were also already mentioned in Section 6.2: Firstly, including crossdocking activities, mode transfer without yard waiting time, to the simulation is assumed to result in significant effects for terminal throughput times; Secondly, linking truck distribution planning to the barge arrival forecasts in combination with crossdocking, assuming an increased crossdocking performance.

References

Carteni, A., & de Luca, S. (2012, February). Tactical and strategic planning for a container terminal: Modelling issues within a discrete event simulation approach. *Simulation Modelling Practice and Theory, 21*(1), 123-145.

Chopra, S., & Meindl, P. (2013). Supply Chain Management. In S. Chopra, & P. Meindl, *Supply Chain Management* (pp. 205-207). Edinburgh Gate: Pearson.

Crainic, T. G., & Kim, K. H. (2007). Chapter 8 Intermodal Transportation. In C. Barnhart, & G. Laporte, *Handbooks in Operations Research and Management Science* (pp. 467-537). Amsterdam: Elsevier B.V.

Gambardella, L. M., Mastrolli, M., Rizzoli, A. E., & Zaffalon, M. (2001, October). An optimization methodology for intermodal terminal management. *Journal of Intelligent Manufacturing, 12*(5), 521-534.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory : strategies for qualitative research.* Chicago: Aldine Pub. Co.

Google MyMaps. (2017, July). Retrieved from https://www.google.com/mymaps

Kozan, E., & Casey, B. (2007, September). Alternative algorithms for the optimization of a simulation model of a multimodal container terminal. *Journal of the Operational Research Society, 58*(9), 12003-1213.

Lowe, D. (2005). *Intermodal Freight Transport.* Amsterdam: Elsevier Ltd.

Macharis, C., & Bontekoning, Y. (2004, March 1). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research*, pp. 400-416.

Marinetraffic.com. (2017). Retrieved from http://www.marinetraffic.com

Maurutto, R. (2016, October). Mit 3600 PS nach Antwerpen und zurück. *Kölner Hafenzeitung, 8*(3), p. 3. Retrieved from http://www.hgk.de/images/downloads/hafenzeitung/hafenzeitung-03-16.pdf

Möller, D. P. (2014). 6.3 Container Terminal Simulation. In D. P. Möller, *Introduction to Transportation Analysis, Modeling and Simulation* (pp. 247-257). London: Springer-Verlag.

Möller, D. P. (2014). 6.4 Intermodal Container Terminal Simulation. In D. P. Möller, *Introduction to Transportation Analysis, Modeling and Simulation* (pp. 257-274). London: Springer-Verlag.

Pouloudi, A., & Whiteley, E. A. (1997, March). Stakeholder identification in inter-organizational systems: gaining insights for drug use management systems. *European Journal of Information Systems, 6*(1), 1-14.

Rizzoli, A. E., Fornara, N., & Gambardella, L. M. (2002, May). A simulation tool for combined rail/road transport in intermodal terminals. *Mathemathics and Computers in Simulation, 59*(3), 57-71.

Robinson, S. (2014). *Simulation: The Practice of Model Development and Use* (2nd ed.). Hampshire: Palgrave Macmillan.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students.* Edinburgh Gate: Pearson Education Limited.

Sideris, A. C., Boilé, M. P., & Spasovic, L. N. (2014, September 4). *Publication: ResearchGate.* Retrieved June 1, 2016, from ResearchGate: https://www.researchgate.net/publication/237291662_USING_ON-LINE_INFORMATION_TO_ESTIMATE_CONTAINER_MOVEMENTS_FOR_DAY-TO-DAY_MARINE_TERMINAL_OPERATIONS

Yellowstar. (2017, June 15). *About Us: Yellowstar Solutions*. Retrieved from Yellowstar.com: https://www.yellowstar.com/en/about-us/

Appendix

Appendix 1: comparison of forecast methods

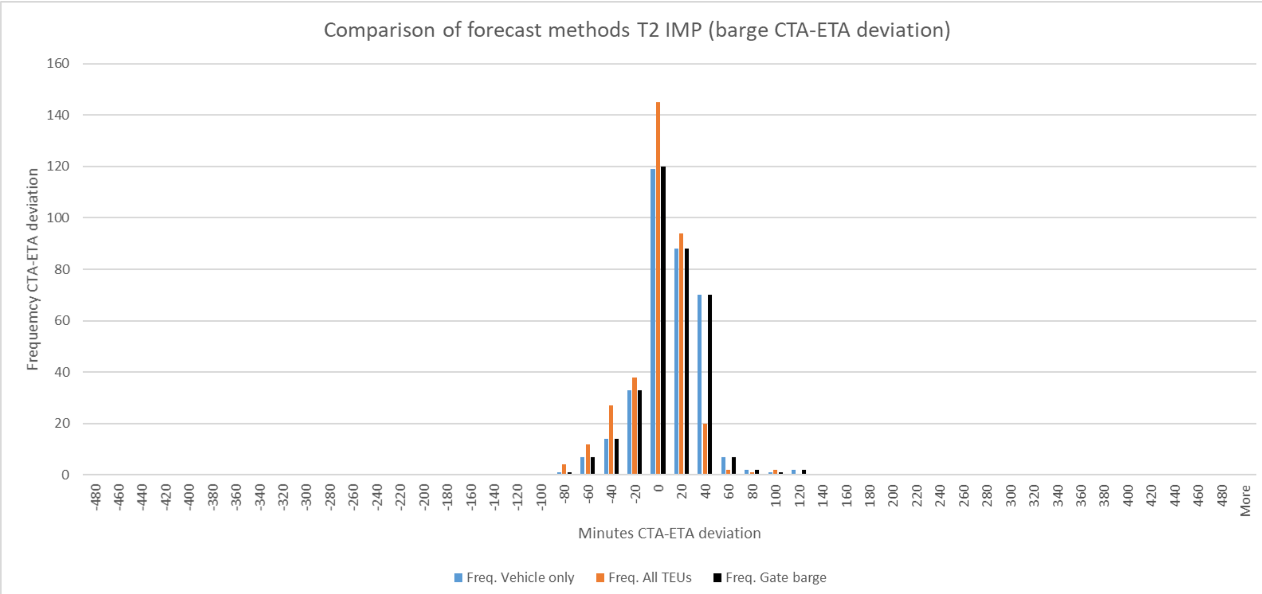

Figure 20 comparison of forecast methods terminal 2 import (CTA - ETA deviation)

Table 18 forecast error analysis terminal 2 Import

Forecast method	MSE	MAD	bias
vehicle only	681	19	-1243
all TEUs	720	17	2272
gate barge	679	19	-1243

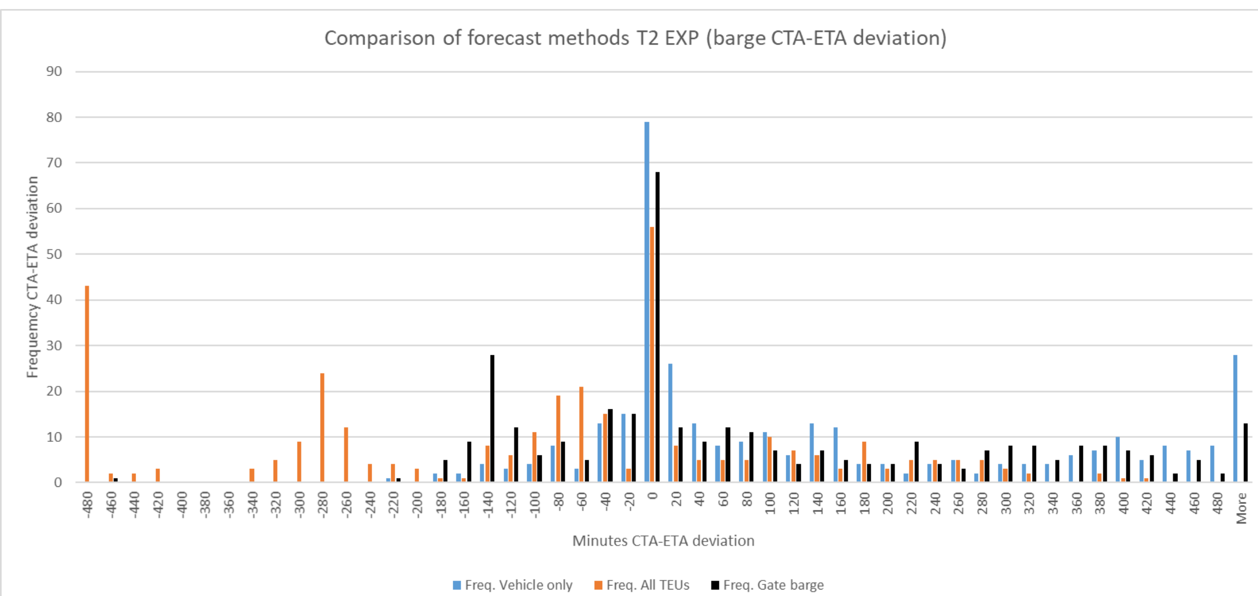

Figure 21 comparison of forecast methods terminal 2 export (barge CTA - ETA deviation)

Table 19 Forecast error analysis Terminal 2 export

Forecast method	MSE	MAD	bias
vehicle only	61684	165	-47278
all TEUs	79334	200	41509
gate barge	44978	150	-28451

Appendix 2: terminal observations per department

Appendix 2.1 observations Customer Service (CS) department

Appendix 2.1.1 main tasks (CS)

The main tasks of the Customer Service department are the following, in chronological order of appearance during a voyage:

- **Check incoming orders**
  About 100 orders per day are received by the Customer Service (CS) by three different methods. The first one is a booking per phone, the second one a booking per mail, and another method for large customers is the booking via the OCL system, a digital booking environment. After receiving an order by phone or mail, the booking is checked upon plausibility and copied to the 'Documar'-system, which is an internal platform of the terminal for sharing documents among all employees. To make the information of the order and preferred voyage available for the barge operator, the order must be registered in the CMS manually and is then synchronized with the Barge Management System (BMS) of the barge operator. Besides the registration for the barge/rail voyage, a disposition slot must also be booked by the CS to ensure that the container will be transferred by truck between the terminal and the inland address.
  Bookings via the OCL system are automatically synchronized with the CMS of the terminal and have priority among other bookings. A fixed amount of disposition time slots is also blocked for OCL bookings.

- **Communicate with customers during a voyage**
  The CS is in contact with all customers and communicates wishes of the customers with other departments, or informs customers about changes during the voyage. Changes occur mainly in form of rescheduling of barge or train voyages, for example the container will be shipped with an earlier voyage than initially intended, delays of barges or trains, or there are some delays regarding the disposition. Information about voyage changes are provided by the Barge & Rail department, and information about truck delays regarding the disposition is provided every 15 minutes by the Disposition department via an Excel list. The CS should be also automatically informed about truck delays by the 'Track&Trace'- and the 'Driver'-Application, where delays should be reported by truck drivers.
- **Handle cancellations**
  If a booking is cancelled by a customer, the CS needs to change the transport method of the affected containers in the CMS to 'TRUCK', which leads to a deregistration of the container in the BMS of the barge operator. Often, an additional email is sent to the barge operator to ensure that the deregistration is noticed.

Appendix 2.1.2 summary of information requirements (CS)

The main information required by the CS regarding a new booking are: the closing date for the latest arrival at the sea terminal, the inland closing day for the latest arrival at the hinterland terminal, the shipping day as the day of loading and departure of the sea ship, the "Posi-No." as the identification number for orders of customers, and the amount, type and weight of containers.
Regarding changes during a voyage, the CS relies on precise information about delays, for barges, rails or trucks, as early as possible from the Barge&Rail or Disposition department.

Appendix 2.1.3 potential points of improvement (CS)

Some observations highlighted aspects which could be part of future improvements for the work at the CS department. A first aspect is the strengthening of general trust in the internal Information System (IS). It can be observed that some communication is done twice, as could be seen by the communication about truck delays, where on the one hand the CS should receive automatically a notification when a truck driver reports a delay, an on the other hand the information is again shared via an Excel file by the Disposition department. Another example is the notification of cancellations for the barge operator, where obviously some uncertainty exists regarding the visibility of the cancellation at the barge operator, leading to a parallel communication via email.
To strengthen the trust in the IS and to reduce the use of parallel systems, it could be an option to critically reflect on which information is received by each communication method. If all notifications on delays provided by the Excel file are identical with the notifications from the IS, the is no need to further use this parallel messaging system. If this is not the case, the IS not fully fits the requirements and some research in cooperation with the disposition department needs to be undertaken to identify and solve the causes. In general, it could help to clearly communicate to employees how their sent notifications are received by other departments. Yellowstar could (again) inform top managers of departments about the IS communication, for example by showing the CS how the barge operators receive notifications about cancellations. It is also an option that department managers of different departments, for example the CS and barge operators, reflect together on the communication methods.

A second aspect is the option to increase the usability of the IS by small changes. There is obviously the need to store and share documents. Further research could be done towards the need of the inclusion of a document database in the CMS, or to create a link to the used system 'Documar'. Another improvement for the usability could be a more logical cancellation option for the CMS. To set a container transport option to 'TRUCK' with the aim to cancel a voyage sounds not like the most logical way. A more logical way to cancel voyages and synchronize it with the BMS could also lead to a higher trust in related IS communication.

Appendix 2.3 observations Barge & Rail (B&R) operations department

Appendix 2.3.1 main tasks (B&R)

The main tasks of the Barge & Rail operations department are the following, in chronological order of appearance during a voyage:

- **Rescheduling of container-voyages**
  One main task of the B&R department is the rescheduling of container-voyages, which is mainly the shift of already planned containers to an earlier, not fully utilized voyage. Rescheduling takes place about three days prior to the start of a voyage and often trains need improvements

regarding utilization, since most of the bookings are initially intended and booked by the CS for barge voyages. Therefore, trains are often not fully utilized, but are paid per complete train and not per container loaded. To update the voyage information within the CMS and BMS properly, the employee must change the transport mode of a container in the CMS first to 'TRUCK', to delete the entry in the BMS, and then to 'TRAIN', which re-enters the information in the BMS with the updated voyage. The request for a rescheduling is sent by the barge operators.

- **Check of loading lists**
  Another task of the B&R department is the check of loading lists for barges and trains every day at 4 pm one day before the arrival of the barge/train. This is the closing time at which the barge operator needs to know the exact number of containers to be loaded at the hinterland terminal. To check the loading lists, the lists with containers per voyage are printed out and compared with information from the CMS. The argument of employees to use extra printouts is to have a better overview of the containers checked. For all containers, it is checked whether they are on time at the hinterland terminal and whether all documents are available (Ausfuhr-Begleit-Dokument ABD, Freistellung) and printed, "as requested from Rotterdam'.
  If there are some changes regarding the loading list after the closing date, the captain of an affected barge needs to be informed via mail, enabling him/her to adjust the stow plan for the barge. Changes occur often due to short-term cancellations from large customers, who block a fixed amount of container places at each barge permanently.

- **Communication with barge/train operator during a voyage**
  During a voyage, the B&R department is responsible for the communication with the barge/train operator. Main communication is about expected arrival times (ETAs) of barges for the next day, where the barge operator sends daily an Excel list with ETAs for each terminal along the voyage route. If some changes occur regarding the ETAs, an updated Excel list may be sent several times a day. Information about ETAs should be also available via the CMS, which is linked with the BMS of the barge operator, but employees are unsure about the correctness of the information provided, and lacking a visual notification when a change occurs. Furthermore, real-time information about ETAs should be available soon due to the implementation of a Track&Trace solution for barges, called i&Land. After receiving the ETAs, the information is entered manually in an external, digital calendar, which is shared among all relevant departments.

  If a delay occurs, the B&R department changes the voyage information for all containers and sends a list of affected containers to the Disposition department and the CS, who may need to contact customers because of the delay. Furthermore, for all containers which are intended to be loaded onto the delayed barge it is checked whether the voyage is still within the time limits of the container bookings. Otherwise, containers need to be rescheduled.

- **Creation of crane job lists**
  When a barge or train arrives, the B&R department receives a request from the Control Station to create a job list for the cranes. This job list contains information for the cranes about which container to move when to which place, from or to the barge. The B&R department compares the stow plan with the loading list and creates the crane jobs accordingly. Job creation is an automated

process and the created jobs are digitally available for crane operators via the RF-Mobile application on a display.

- **Check of KWZ (Kleinwasserzuschlag)**
  One day after the barge departure at the hinterland terminal, the barge operator sends information about the water level during the voyage. A low water level can lead to higher costs for each container moved. The B&R department looks for affected containers and informs the CS to contact associated customers.

Appendix 2.2.2 summary of information requirements (B&R)

Each task of the B&R department has different information requirements. To reschedule containers, time restrictions of containers must match the voyage parameters, and all documents must be available. Some customers also restrict their containers to be moved only by a preset modality. Furthermore, only the port of Rotterdam is reachable via train, not the port of Antwerp. And finally, the destination within the port of Rotterdam may not be too far away from the arrival point of the train, since the intern transport at Rotterdam may lead to extra cost.

Looking at the communication about ETAs of barges, the B&R department needs updates as early as possible, since they are responsible to share this information among other departments, influencing the planning of the pre- and end-haulage, customer satisfaction, and the scheduling of crane operators.

Appendix 2.2.3 potential points of improvement (B&R)

After observing the B&R department, it seems like changes in the visual representation of information within the IS could be a potential valuable point of improvement. Employees use, for example, an external calendar or printed lists because they obviously feel that the IS lacks some comfort regarding the representation of relevant information. Adding a calendar where changes in ETAs and delays are visually clear represented, or a sort of a color scheme to aid the selection of suitable containers for rescheduling or to enable the employees to check loading lists more comfortable within the CMS, may increase the acceptance for the IS and can lead to a reduction of parallel system usage. In general, a reduction of paper usage could be seen as an ecological valuable and cost-effective option.

A second point is based on the insight that the scheduling of trains seems somewhat unpredictable. Further research could be done to analyze whether a reduction of rescheduling activities, through for example more direct bookings on trains, could lead to a more efficient yard and disposition planning, influencing the container and vehicle throughput times due to, for example, shorter crane processing times.

Appendix 2.3 observations Pre- & End-haulage (P&E) planning department

Appendix 2.3.1 main tasks (P&E)

The P&E department handles a special sort of booking from an external train operator (DB). They do not plan a complete voyage, but receive information about expected container arrivals and departures and asked to plan the distribution by truck for these containers. The main tasks of the P&E department are the following, in chronological order of appearance during a voyage:

- **Plan truck dispositions for DB-train voyages**
  The P&E department receives a request for a truck disposition via an automatically printed fax. The fax is transmitted via an external information system, which is called 'Infokette' and is linked to an external booking and CMS system called 'Transfracht'. The P&E department checks whether there exists a suitable free time slot in the 'Dispomatrix', a list to plan future dispositions., and accepts the request if possible. After selecting a time slot, all information regarding the container transport should be filled in manually in the CMS and the Transfracht software.

- **React on changes in voyage planning**
  If changes occur in the voyage planning, the P&E department receives a notification via email. Employees state that there is no good insight in the importance of the email, or whether it is of relevance for them at all. In case that there is a relevant change, employees need to fill in all relevant information for the disposition of the containers again in both information systems, Transfracht and the internal CMS.

- **Check and print all disposition jobs**
  Two days before the truck disposition takes place, the disposition orders for each container are printed out and checked again one day before the actual disposition. After the check is complete, the printed-out disposition orders are handed over to the Disposition department.

Appendix 2.3.2 summary of information requirements (P&E)

The P&E department needs mainly information from the train operator on planned arrival and departure times of containers at the terminal, to be able to plan a truck distribution. Additionally, information on changes in the voyage planning by the train operator need to available for the P&E department as early and clear as possible.

Appendix 2.3.3 potential points of improvement (P&E)

Since the information systems the P&E department works with are not managed by the terminal, the options for improvement by the terminal or Yellowstar are limited. Further research needs to be done to determine whether a link of the different information systems is possible, which could be used for automatically updating the CMS of the terminal.

Appendix 2.4 observations Disposition department

Appendix 2.4.1 main tasks (Disposition)

The main tasks of the P&E department are the following, in chronological order of appearance during a voyage:

- **Assign disposition orders to trucks**
  Main task of the Disposition department is the assignment of disposition order to trucks. Most of the disposition orders are assigned one day before the actual disposition takes place. It starts with a request from a truck driver for a job. The disposition department looks up a suitable job from the disposition list and hands over the printed-out disposition order to the truck driver. To make the assignment visible within the CMS and in the Driver application of the truck driver, the driver and the container entries are connected within the CMS via drag and drop. The driver can now see the order in his or her personal driver application and is able to indicate start, stop, and special events.

The employees of the Disposition department also print out the disposition lists, with the argument that they have a better overview and more possibilities to add notifications for employees of later shifts.

- **React on problems during a truck disposition**
  If a problem occurs during the truck disposition, like heavy traffic or other delays, the truck driver is asked to report this via the driver app or phone. The disposition department receives this information in form of a notification within the CMS and collects all delays to add them to an Excel list they send every 15 minutes to the CS department. Additionally, the incoming notification of a delay in the CMS should automatically be forwarded to the CS, without any additional actions undertaken by the Disposition department.

- **Reschedule truck dispositions**
  If there is a heavy delay expected for barges or trains, the disposition department needs to check all disposition orders upon their executability, and reschedule them when needed.

Appendix 2.4.2 summary of information requirements (Disposition)

The main information on planned truck dispositions are visible at the disposition list, which is earlier filled in by the P&E and CS departments. The disposition department relies on quick and reliable information on delays, which can be truck arrival delays (truck drivers), barge or train arrival delays (B&R), or cancellations (CS). Since the Disposition department assigns most of the orders one day prior to the requested delivery date, the disposition list needs to be filled as complete as possible until this date. The disposition list is already several weeks before the due date available for other departments.

Appendix 2.4.3 potential points of improvement (Disposition)

After observing the Disposition department, some suggestions for potential points of improvement regarding the software and the workflow can be derived. One observed aspect was already described for the CS: the use of parallel communications systems, like the periodically sent Excel lists on truck delays besides the notification via the IS, because of a lack of trust in the IS. As already described for the CS, some change management with clear communication about the relevant functionality of the information system for each department could help to reduce the use of parallel systems.

A second observed aspect is the use of extra printed disposition lists, besides the option to fully perform the assignment tasks in the IS. As reason behind this, employees mention that the IS lacks some overview over all containers, since they disappear from the digital disposition list after assigning them to a truck driver, and that notifications for containers from other employees of the Distribution department are not easily enough to access and visible within the IS environment. Further research could be done to evaluate detailed improvements for the usability of the IS.

Another aspect is related to the workflow within the department. Since most of the distribution orders are assigned to drivers one day before the actual distribution needs to take place, the occurrence of crossdocking crane events can be assumed to be random, with a relative low chance of occurrence. Thinking about crossdocking crane events as a high potential to decrease barge and train throughput times drastically, by reducing the total number of needed crane movements per day, it could be a valuable change in the workflow when the assignment of distribution orders is performed more on a short-term basis with a higher focus on archiving crossdocking events. Further research needs to be done to evaluate the potential effectiveness of such an adjustment of the workflow.

Appendix 2.5 observations Control Station (Leitstand)

Appendix 2.5.1 main tasks (Control Station)

The main tasks of the Control Station are the following, in chronological order of appearance during a voyage:

- **Receive documents from Barges**

One day before the barge or train arrives at the terminal, the barge captain sends the definite load and delete list, and the stow plan via mail to the Control Station. The Control Station sends this information to the B&R department, where the crane jobs to process the arriving barge or train are created.

- **Request crane and reach-stacker operators**

Crane and reach-stacker operators are no full-time employees of the terminal, but need to be requested each day before 2 pm from an external worker pool. The Control station decides each day, at the given time limit, how many crane operators are requested per shift for the next day, based on the known ETAs of barges and trains at the given time. The cranes of the terminal run nearly 24 hour each day, with an exception on night shifts during the weekend.
Employees of the Control Station indicate that the ETAs of barges are very unreliable, often with deviations of more than 6 hours, leading to an ineffective allocation of crane operators to shifts, since barge may arrive than in another shift than expected.

- **Allocate crane and reach-stacker operators to machines**

During the working shifts of cranes and reach stackers, the Control Station decides at which machines the requested operators work. There are, for example, the two main quays with 3 cranes which can be utilized, and another quay with a crane for empty containers.

- **Define stop positions of trucks at the quays**

When a truck arrives at the terminal, it needs to be loaded or unloaded by an active crane. The truck stops for this purpose at the Control Station, where the truck driver receives a precise stop position at the quay. The RF-Mobile application, which is used to assign container movement jobs to cranes, cannot detect where a barge is located at the quay, and therefore cannot assign a precise truck stop location automatically.

Appendix 2.5.2 summary of information requirements (Control Station)

The Control station needs mainly precise information on ETAs of barges and trains, from the barge and train operator, one day before the arrival of the vehicles., to request and assign crane operators properly. The employees of the Control station would like to receive the ETAs in form of a calendar entry, to ensure a good readability and to provide a simple visual overview over arrivals and crane shifst. Furthermore, the employees of the control station need to know the precise location of the barge at the quay to assign suitable truck stop locations to arriving trucks.

Appendix 2.5.3 potential points of improvement (Control Station)

After observing the Control Station, it seems like their task of requesting and assigning crane operators may have a main impact on the performance of the terminal, since a wrong utilization of crane capacities may lead to an increase in processing and waiting times of transport vehicles at the terminal. Since the employees of the Control Station indicate that the prediction of arrival times of barges is very unreliable, further research could be done to analyze why the forecasts may not fit the reality well, and how to improve these forecasts.

Another point of improvement may lie in some adjustments in the RF-Mobile application. By adding some options to indicate the position of barges and active cranes at the terminal, suitable truck stop locations could be assigned automatically. To reduce the time a crane needs for a job to load a truck, the location of the container to be loaded, or the position to which a container is unloaded could be integrated in the calculation of an optimal truck stop location.

Appendix 3: terminal processes and related communication (process map)

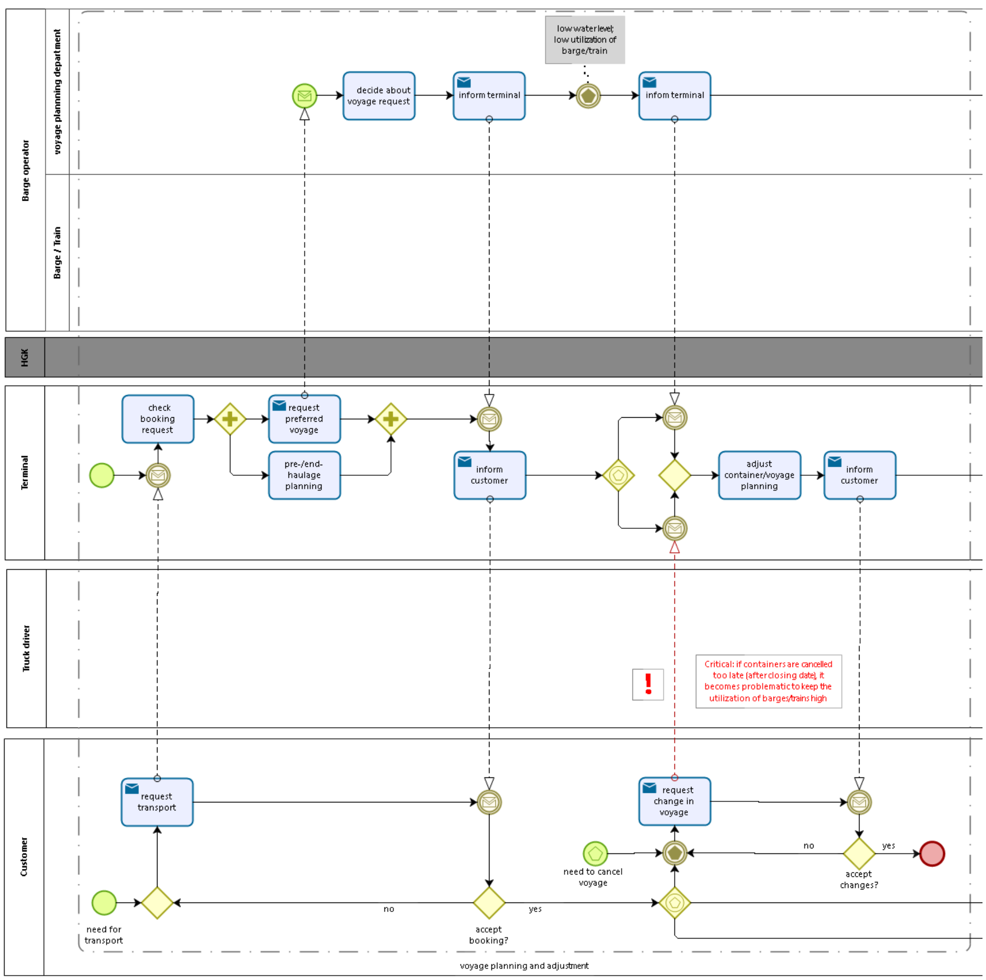

Figure 22 appendix 3.1 terminal process map: voyage planning and adjustment

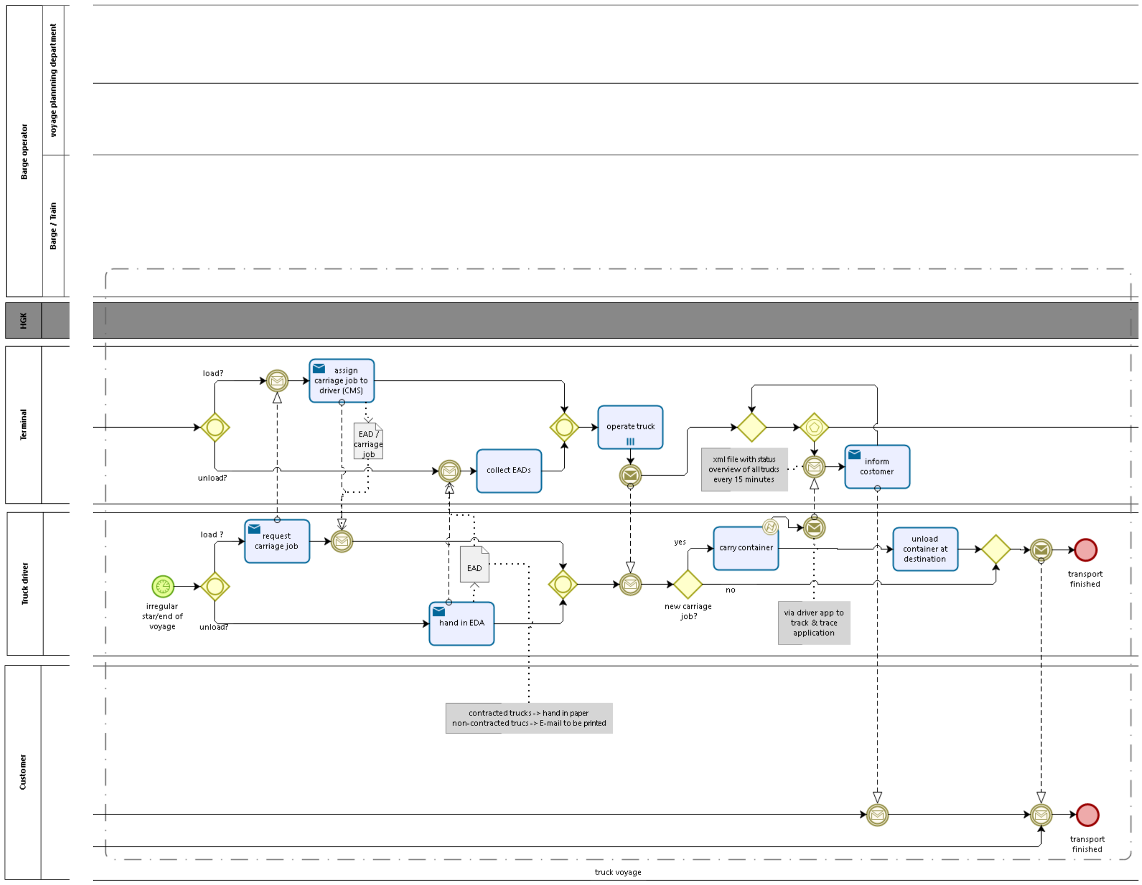

Figure 23 appendix 3.2 terminal process map: truck voyage

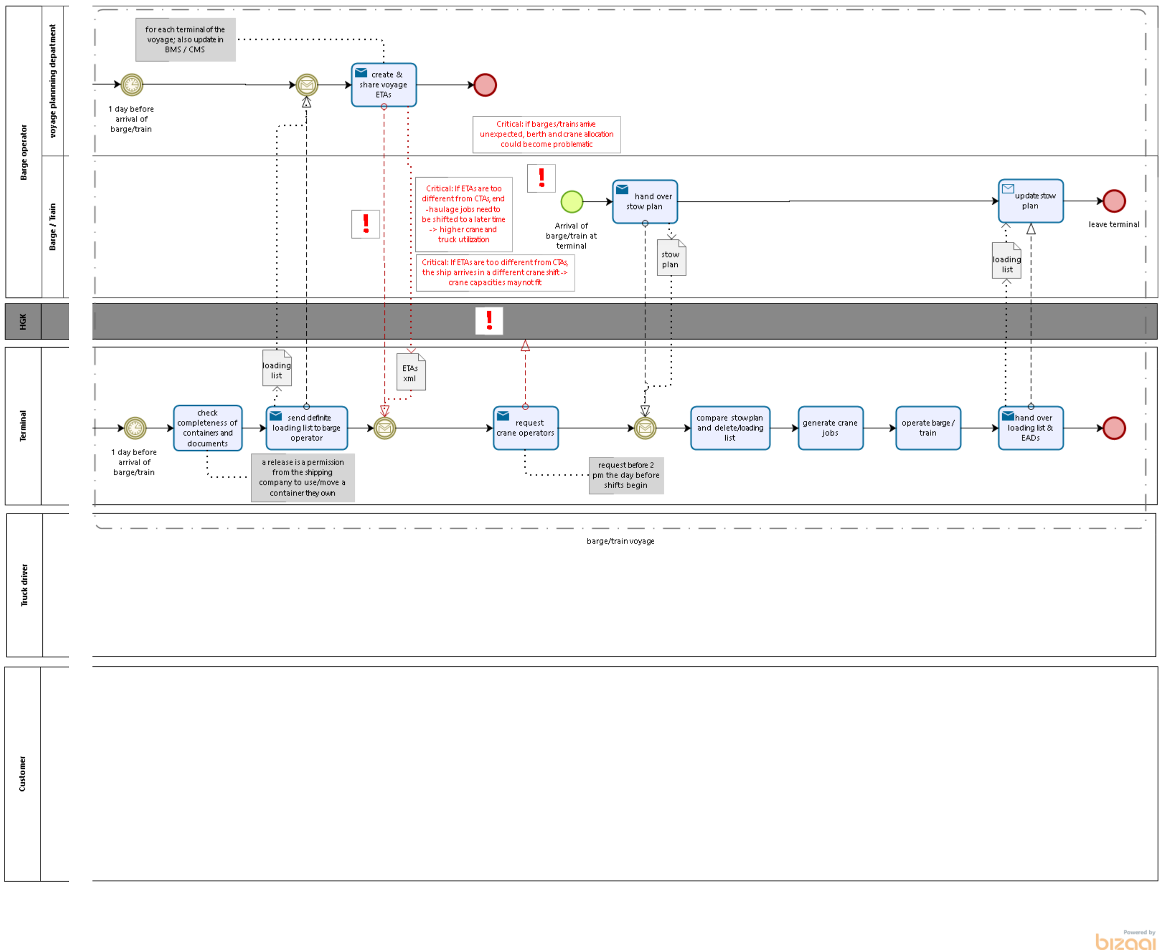

Figure 24 appendix 3.3 terminal process map: barge/train voyage

Appendix 4: simulation model scope and level of detail

Appendix 4.1 model scope

Table 20 intermodal hinterland transport terminal illustration: model scope

Component	Include/Exclude	Justification
Entities:		
Containers	Include	Flow through the process
Trucks	Exclude	Too complex, tracking of containers is sufficient
Barges	Include	Main transport vehicles, flow through the process
Trains	Include	Main transport vehicles, flow through the process
Activities:		
Cranes	Include	required to simulate container movements and utilization
Reach-stacker	Exclude	Too complex, barges can only be processed by cranes
Gate	Include	Relevant to create or delete containers
Control station	Exclude	Assumption: Not relevant for waiting times
Queues:		
Berth queues	Exclude	Barge waiting will be controlled by sensors
Crane queues for trucks	Exclude	Containers represent trucks
Crane queues for containers	Include	represents the terminal yard; multiple queues are needed to simulate in-terminal movements
Yard	Include	Needed to store containers
Gate queues for trucks	Exclude	Assumption: gate queues are not a significant problem
Control station queues	Exclude	for trucks between crane and gate; Assumption: not significant for truck waiting times
Crane queues for trains	Exclude	Train waiting will be controlled by sensors
Resources:		
Crane staff	Include	Important to simulate capacities of cranes per shift
Gate staff	Exclude	Gates are not simulated
Control station	Exclude	Control station is not simulated

Appendix 4.2 model level of detail

Appendix 4.2.1 level of detail: entities

Table 21 intermodal hinterland transport level of detail: entities

Component	Detail	Include/Exclude	Justification
Entities:			
Containers (TEUs)	Quantity: 1 entity represents 1 container	Include	each container has an individual flows and attributes
	Arrival pattern (start at terminal): based on arrival pattern for trucks; % of trucks bring a container (start at barge/train): created together with a barge or train	Include	required to model container demand
	Attributes: weight, load, type, size, release	Exclude	Assumption: not relevant for service time (duration of container movements)
	Attributes: destination, voyage type	Include	Required to unload containers at the right terminal and for further routing of the container
	Routing: via gate in to truck queue, crane, yard, yard queue, crane, modality **OR** via barge/train to crane, yard, yard queue, crane, gate out	Include	Routing based on destination and voyage type of the containers
Barges	Quantity: 1 entity represents 1 barge	Include	movement of single barges during the voyage is relevant for outputs
	Arrival pattern: for scheduled barges -> scheduled start times at start terminal with some deviation	Include	the total barge voyage time is part of the outputs; fixed barge schedule represents reality
	Attributes: travel speed, destination	Include	Simplification: fixed travel times between terminals, effects on total travel time only based on terminal operations
	Attributes: capacity	Exclude	Simplification: all assigned containers will be moved
	non-conformities	Exclude	Assumption: no breakdowns during the voyage

	Routing: some barges have a fixed voyage scheme and need to stop at predefined terminals, based on their origin/destination	Include	assigning barges to the right terminal is important to determine crane utilization correctly
Trains	Quantity: 1 entity represents 1 train	Include	waiting times of individual trains is part of the outputs
	Arrival pattern: for scheduled trains -> scheduled start times at start terminal with some deviation	Include	the total train voyage time is part of the outputs; Fixed train schedule represents reality
	Attributes: travel speed, destination, capacity	Include	Simplification: fixed travel times between terminals, effects on total travel time only based on terminal operations; trains stop at different terminals; some trains have different capacities
	non-conformities	Exclude	Assumption: no breakdowns during the voyage
	Routing: some trains have a fixed voyage scheme and need to enter special terminals	Include	assigning trains to the right terminal is important to determine crane utilization correctly

Appendix 4.2.2 level of detail: activities

Table 22 intermodal hinterland transport level of detail: activities

Component	Detail	Include/Exclude	Justification
Activities:			
Cranes	Quantity: # ready to use depends on # crane operators available and terminal	Include	main processing activity at terminal; different terminals may have a different number of cranes
	Nature (X in Y out)	Exclude	simple 1 in 1 out
	Cycle time: service time distribution	Include	influences utilization and waiting times at terminals
	Breakdowns/repairs	Exclude	Simplification: no breakdown events included
	set-up/changeover	Exclude	Assumption: not relevant
	Resources	Include	Crane operators, important to determine number of available cranes

	Shifts: based on scheduled crane staff	Exclude	cranes are 24h available, shifts based on crane staff availability
	Routing: to entity (mode) assigned to container, or another yard queue	Include	depends on movements assigned to a container
	Other: prioritizing	Include	truck operations are prioritized

Appendix 4.2.3 level of detail: queues

Table 23 intermodal hinterland transport level of detail: queues

Component	Detail	Include/Exclude	Justification
Queues:			
Crane queues for containers	Quantity: 3-4 per terminal for processing from/to gate, yard, barge, train	Include	required for waiting time calculations
	Capacity: unlimited	Exclude	Simplification: no limit to number of containers stored
	Dwell time	Exclude	no expected dwell time in queues
	Queue discipline: first-in-first-out	Include	Containers are moved based on their arrival
	Breakdown/repair	Exclude	n/a
	Routing: to crane or an entity (modality)	Include	flow of containers through the terminal
Yard	Quantity: 1 per terminal	Include	Required to store containers at terminals
	Capacity: unlimited	Exclude	Simplification: no limit to number of containers stored
	Dwell time	Include	Containers are scheduled to exit the yard
	Queue discipline: due date	Include	Containers exit the yard based on their due date (pull process)

Appendix 5: literature review: how to model an intermodal hinterland transport network

Appendix 5.1: research execution

Modeling an intermodal terminal can be very complex. To find an adequate balance between accuracy, and run and development speed, a literature research has been performed to aid the conceptual modelling stage as described by the methodology provided by Robinson (2014), which was used for this simulation approach. The main stages of this methodology are: Firstly, conceptual modeling to understand the real-world problem and to develop a conceptual model; Secondly, model coding to make the simulation executable; Thirdly, experimentation to test the accuracy and scenario's, and to adjust the model; Lastly, the implementation of findings of the model. Robinson (2014) states that the methodology is not linear, but it is possible and needed to jump between the stages for adjustments after gaining new insights during the simulation approach.

Robinson (2014) provides a general methodology, but no specific information about how to model an intermodal hinterland transport network. The key-words and databases which are used for a more extended literature research are shown in Table 24. It is decided not to extend the research further, since some papers like the one of Möller (2014) or Carteni & de Luca (2012) provide some gerneal information on terminal simulation, or are a literature summary on this issue, too. Furthermore, the most important source for a realistic simulation is still the observed terminal itself.

Table 24 literature review: search strings & databases

Search string	Scope	Date of search	Date range	Number of entries
Search protocol for FindUT				
"intermodal terminal" AND "simulation"	Title	31.05.2017	all till 2017	41
"containter terminal" AND "simulation"	Title	31.05.2017	2007-2017	236
"hinterland terminal" AND "simulation"	Title	02.06.2017	all till 2017	1
"inland terminal" AND "simulation"	Title	02.06.2017	all till 2017	21
"multiterminal" AND "simulation" AND "container"	Title	02.06.2017	all till 2017	15
Search protocol for IAOR				
"terminal" AND "Simulation"	Anywhere	07.06.2017	all till 2017	4
Search protocol for Emerald				
"hinterland" AND "terminal" AND "simulation"	Anywhere, only with access	07.06.2017	all till 2017	9
"container terminal" AND "Simulation"	Anywhere, only with access	07.06.2017	all till 2017	15
Total				342
Removed based on eclusion criteria				-8
Removed due to duplicates				-28
Removed after reading abstract				-47
Removed due to access restrictions				-26
Removed due to time restricitons				-226
Total in review				7

The following inclusion and exclusion criteria are applied for the research (Table 25):

Table 25 literature review: inclusion & exclusion criteria

Number	Exclusion criteria	Reason for exclusion
1	berth allocation in large sea ports	# of vessels berthing and terminal equipment available is not comparable to the situation in hinterland termials
2	pure air cargo terminals	no pure container handling
3	non-container terminals (e.g. coal)	no container handling
4	rail-rail terminals	lack of modalities, too simple
5	in-terminal transport	too much detail
6	pure berth activites	lack of modalities, too simple

Number	Inclusion citeria	Reason for inclusion
1	inter-/or multiterminal simulations	fits the situation of scheduled barge voyages along several terminals
2	full simulation of large sea ports	besides the separation of berth- and yard area, the processes should be comparable to hinterland terminals

The concept matrix can be found in Table 27. A summary of the review and usage of concepts is provided in Table 26.

Table 26 literature review: summary of concepts

Modelling approach	#	%	key simulation entities	#	%	key activities	#	%
discrete-event	6	86%	external trucks	6	86%	truck (un)loading	7	100%
conntinuous	1	14%	yard cranes	5	71%	in-terminal transfer	6	86%
			containers	5	71%	train (un)loading	5	71%
			yard area	5	71%	vessel (un)loading	3	43%
			internal trucks	4	57%	vessel arrival	2	29%
			vessels	4	57%	train arrival	1	14%
			trains	4	57%	truck arrival	1	14%
			berth cranes	4	57%	berth & crane allocation	1	14%
			dock area	2	29%	internal truck allocation	1	14%
			plains	1	14%	paperwork handling	1	14%
			stackers	1	14%	arc resource allocation	1	14%
			gates	1	14%			
			inter-terminal corridor	1	14%			
			berths	1	14%			

key distributions	#	%	run length	#	%
in-terminal transfer times	4	57%	<3 months	3	43%
crane processing times	3	43%	4-6 months	1	14%
container dwell times	3	43%	7-12 months	1	14%
vehicle inter-arrival times	3	43%	>12 months	0	0%
throughput times	2	29%			
vehicle arrival schedule	2	29%			
arc capacities	1	14%			
vessel processing times	1	14%			
inter-terminal transfer times	1	14%			

Table 27 concept matrix

Journal/book	Article	Authors (Year)	Modeling approach	key simulation entities	key activities	key distributions	run length	Additional notes
Container Terminals and Cargo Systems (papers from the journal OR Spectrum)	Simulation of multiterminal systems for container handling	Ottjes, J. A., Veeke, H. P. M., Duinkerken, M. B., Rijsenbrij, J. C., Lodewijks, G. (2006)	process interaction modeling approach (or "process interaction method")	transporters; containers; transfer units; stacks	transport; transfer; stacking	container arrival pattern based on their "dwell time" (waiting in yard); arrival time of transporters at next route point; process time	17 weeks; 4 weeks till steady-state	modeling approach is a combination of event scheduling and activity scanning
Introduction to Transportation Analysis, Modeling and Simulation	6.3.2 Container Terminal Model	Dietmar P.F. Möller (2014)	discrete-event	ships; trains; trucks; containers; dock-yard vehicles	ship (un)loading; train (un)loading; truck (un)loading; dock-yard movements	inter-arrival times; throughput time	60 days	focus on terminal utilization and maximum throughput
Introduction to Transportation Analysis, Modeling and Simulation	6.4 Intermodal Container Terminal Simulation	Dietmar P.F. Möller (2014)	discrete-event	plane; train; truck; lifts; stackers; containers; carts	plane (un)loading; train (un)loading; truck (un)loading; vehicle movemets; paperwork handling	service times; in-terminal travel times	180 eight hour days (22,5 weeks)	focus on throughput analysis and resource utilization
Journal of Intelligent Manufacturing	An optimization methodology for intermodal terminal management	L. M. Gambardella, M. Mastrolilli, A. E. Rizzoli, M. Zaffalon (2001)	discrete-event based; network of flow	yard areas; cranes; ships	allocate resources to arcs	arc capacities	2950 containers over 10 work shifts	model consits of nodes and arcs connecting the nodes; no single container movements, but
Mathemathics and Computers in Simulation	A simulation tool for combined rail/road transport in intermodal terminals	Andrea E. Rizzoli, Nicoletta Fornara, Luca Maria Gambardella (2002)	Plattform simulation model; discrete-event	platforms; cranes; rails; trucks; gates; storage area; inter-terminal corridor	loading/unloading of ITUs; sorage of ITUs; departure of ITUs	ITU residence time; terminal throughput; train arrival timetable; truck arrival distribution	unknown	simulate the flow of intermodal terminal units (ITU), single or multi inland terminals; platforms as set
Simulation	Simulation-based analysis for hierarchical storage assignment policies in a container terminal	E.U. Guldogan	discrete-event	vessels; cranes; containers; in-terminal trucks; external trucks; storage area	vessel arrival; berth & crane assignment; stacking; yard truck allocation; container pickup and departure	arrival schedules for containers; container waiting times on vessels; in-terminal transfert times of container and vehicles; overall average waiting time of containers	30 days, 16.487 containers moved	purpose to examine terminal processes at different (workload) conditions
Simulation Modeling Practice and Theory	Tactical and strategic planning for a container terminal	Armando Carteni, Stefano de Luca	discrete-event	vessels; cranes; trucks; containers; yard area; docks; berths; shuttles; trains	vessel arrival; truck arrival; (un)loading of vehicles; in terminal container movements	distributions for time durations of activities	365 days (strategic) ;accurracy more important than run lenght for tactical level	highly detailed discrete-event simulation approach for different planning levels (tactical, strategical), differentiating

Appendix 5.2: literature review summary

By looking at the summary of the literature review, some general patterns can be observed. Firstly, discrete-event models seem to be the standard choice for terminal simulations. Only Gambardella et. al. (2001) use some kind of continuous flow network, simulating the time for the transfer of all containers,

but not modelling each separate container. Since cranes at the Neska terminal are handling containers of different modes parallel, a discrete-event simulation seems to be most suitable.
Secondly, key simulation entities are most frequent: external trucks, yard cranes, containers, and a yard storage area. Depending on the sort of the terminal, internal trucks, vessels and trains are also simulated. Internal trucks are mainly used in sea terminals, where the berth area and the yard area are separated and containers need to be transferred within the terminal. This is not the case for the hinterland terminal of Neska, since one crane has access to all modes and the yard at the same time. An entity which should be included is a reach stacker, since they are also used to operate trains.
Thirdly, looking at the key activities, most simulations focus on transfer actions, like in-terminal transfer or transfers from vehicles. In each simulation, containers must arrive at the terminal, but not always are arrival activities explicitly modeled. It is assumed that the reason for this lies in the use of different simulation software and model development methodologies. In the case of the Neska terminal, container movement by crane will be the main activity for the model.