Master Thesis of Industrial Engineering and Management
track: Production and Logistics Management

Decision support for container transport scheduling

A case study at Combi Terminal Twente

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CTT INTERMODAAL TRANSPORT

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Management summary

In times of increasing road congestion, environmental issues, and the growth of the container transport sector, intermodal transport companies seek smart planning tools to improve container transport on timeliness, sustainability, and costs. This research considers the intermodal transport company Combi Terminal Twente B.V. (CTT) as a case study.

CTT provides transport of containers per barge, train, and truck between the regions Rotterdam and Twente. Barges and trains are used for the long haul and trucks transport the containers between CTT's inland terminals and the loading/discharge addresses. CTT is growing and sees opportunities to improve the performance of container transport. Growth can be achieved by using information of containers, requirements of customers, resource availability, and the increasing number of containers and types of resources, but is limited by the handling capacity of the planners.

The main research question of this thesis is:

How can we give decision support to CTT's truck planners to improve the performance of timeliness and costs of container transport per truck?

The proposed model supports scheduling on latest departure time, calculating the minimum number of trucks needed for a day, and providing an initial solution for one day. The benchmark situations are constructed by sorting the jobs on latest departure time or randomly, and then allocates the jobs on the truck with which the container arrives as first. A simulated annealing heuristic is used to gain a better performance than the benchmark situation. This algorithm starts with an initial solution, which is a schedule for each truck with the allocated containers. By moving and swapping the containers from one truck to another and crossing of routes, the algorithm seeks for solutions with a better performance.

The solution method is tested with different planning scenarios and settings for the simulated annealing algorithm and are based on an actual operation day. We consider the following scenarios: the original decoupling and loading/discharge times at customers, no decoupling allowed at customers, always decoupling at customers, no loading/discharges times, and different lengths of time periods. For the simulated annealing algorithm, we test the optimization goal, improvement operators, number of jobs for improvement operator, and the stop criterion. The key performance indicators are related to timeliness and costs.

The proposed process in the thesis of gaining an initial schedule for one day is difficult, because there are four different software programs and a programming language needed. This challenge that we had to overcome resulted in the end in a better performance than the benchmark situations.

The benchmark situations perform well for the loading/discharge time related KPIs. The difference between timeliness and costs related KPIs is clear in the time window related KPIs, in which the number of missed time windows decreases from about 55 to around 5. For the minimization of the number of trucks, the benchmark situation performs better than the minimization of trucks as optimization goal. The best result is 36 trucks in the benchmark case, and 37 when minimizing the trucks. The worst performance is when we optimize the total number of containers before the LD time, because there are 48 trucks needed to deliver the containers in time. Minimizing the total travel time can be done by minimizing the travel time or minimizing the total time of detours, which results in about 6.5 and 7 days of travelling, compared to almost 8.5 days in the best benchmark case. For the waiting time we can also optimize 'Time after LD time' or the time window related KPIs, but the minimization of waiting time still performs the best as expected. The total waiting time can be reduced from 3 days in the best benchmark case to about 16 hours in the normal situation. Reducing the number of detours and time of detours can be done best by reducing the time of detours. This reduces the number of detours from 129 to 78, and the time of detours from almost four days to almost 1.5 days.

Before implementing the solution methods proposed in this thesis in practise, more research needs to be done to the sensitivity of the model parameters, such as the time needed for decoupling and loading and discharging time of a container. These parameters differ per loading/discharge address, but are all assumed to be equal in the model. For further improvement we recommend to incorporate actual travel times based on GPS data, instead of an average speed for a certain distance. These adjustments can easily be changed in the model. Another limitation is that we use a data set of one day, and therefore do not see if we can already do some jobs for the next day.

We recommend to validate the model parameters mentioned in the paragraph above and to automate the process of gathering input data of the containers and trucks. Further research needs to be done to the transport dates of a container, because it might be better to transport containers at another day. Also the extension to intermodal and synchromodal transport needs more research. In this way we will not only be able to provide intermodal transport from Hengelo to Rotterdam, but also extend it to other continents.

This research shows that information overload is not a problem, but a possibility to improve the performance of container transport.

Preface

Seven years ago I started my great student life with the bachelor of Applied Mathematics. The atmosphere and the small scale in Enschede convinced me to start studying here, which I do not regret. After five years, with making new friends, sports, working, a board year at D.B.V. DIOK and at W.S.G. Abacus, I started with the master Industrial Engineering and Management. Between the two years of the master I went to a very nice and fun Summer School in beautiful Slovenia, which is one of the best decisions I have made. But for now, I am presenting you the result of my master thesis at Combi Terminal Twente in Hengelo.

Before I started my graduation assignment, my knowledge of trucks and containers was very limited. However, courses in my master attracted my attention into logistics, so this was a great opportunity to get in touch with this field. Even though CTT is called 'a little piece of Rotterdam in Twente', I was surprised the first time that I went there and to see that it is far from being little.

I would like to thank all the colleagues at CTT for sharing their knowledge with me. One of the first things I heard is that it is a very complex world and that it is very difficult to understand what is happening and why things are happening. I accepted the challenge, but I have to say that I am still surprised about all the processes that are going on at CTT and that I still learn many things, and that I still have to learn many more things before I would understand everything.

In particular I would like to thank my supervisors. Danny, thank you for sharing your knowledge and letting me think twice about assumptions I made. Maurice, thank you for your helicopter view on this research and the suggestions to choose a different path in the research as I was doing at that moment. Martijn, thanks for introducing me this assignment and your feedback on my thesis. Marco, thanks for your help with structuring my thesis and the solution method. And Arturo, thanks for your feedback regarding the results in the last phase of my graduation assignment.

Finally I would like to thank my boyfriend Bart for helping me with my thesis and listening to all the frustrations when the model did not do what I wanted it to do. Furthermore, friends, fellow students, housemates, and family: thanks for being there in my great student life. For now it is time to bring a little piece of Twente to Rotterdam!

Inge Krul

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List of definitions

Barge	Ship used for transporting containers at inland waterways. Smaller than sea ships, because the waterways are smaller.
Demurrage costs	Costs related to storing a full container after a number of days.
Detention costs	Costs related to storing an empty container after a number of days.
Empty depot	Depot nearby sea terminal to store empty containers.
Empty miles	Distance travelled by truck without container.
First mile	Transport from customer by truck to inland terminal.
Handling	Transshipment of one mode of transport to another mode.
Intermodal transport	Combination of multiple modalities to transport the load from origin to destination in one and the same intermodal transportation unit (a container).
Job	Moves of container at one day. This could be one more, for example, from an inland terminal to a LD address, or multiple moves, for example, from inland terminal to LD address and back.
Last mile	Transport by truck from inland terminal to customer.
LD address	Loading/discharge address. The location where the container is discharged or loaded before further transportation.
Long haul	Transport by barge or truck from Rotterdam to an inland terminal (Hengelo, Bad Bentheim or Almelo), or vice versa.
Move	The transport of a container between two locations.
Plan	Result of planning.
Planner	The person who schedules the containers.
Planning	The process of identifying all resources and activities necessary to complete the project.
Schedule	Result of scheduling.
Scheduling	The process of determining the sequential order of activities, assigning planned duration and determining the start and finish times of each activity.
Synchromodality	The optimally flexible and sustainable deployment of different modes of transport in a network under the direction of a logistic service provider, so that the customer (shipper or forwarder) is offered an integrated solution for his (inland) transport.
TEU	Twenty-feet Equivalent Unit, a container with a length of 20 feet.

Chapter 1

Introduction

Road congestion, traffic safety, and environmental issues force transport companies to find new solutions for intermodal container transport (Macharis, Caris, Jourquin, & Pekin, 2011). Transport by truck is a fast transport mode compared to inland barges and trains, but it is expensive and not environmentally friendly. A modal shift from trucks to barges and trains already decreased CO_2 emission to reduce environmental issues, but smart planning tools are needed to further improve sustainable container transport on different modes of transport.

Figure 1.1 shows from left to right an example of a transport of a container. Sea ships transport containers from all continents to, amongst others, the Port of Rotterdam, the main port of The Netherlands. From here, inland barges and trains transport the containers to inland terminals. Trucks transport containers for their last part to distribution centres, in which the goods are unpacked from the container on pallets and transported by delivery vans or trucks to shops and consumers.

Figure 1.1: Transport of a container from manufacturer in China to distribution centre in Twente.

This combination of using different modes, or modalities, of transport is known as intermodal transport. Macharis and Bontekoning (2004) define intermodal transport as '*the combination of at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route traveled by rail, inland waterway or ocean-going vessel, and with the shortest possible initial and final journeys by road*'. The shipping line[1] and shipper[2] agree upon the modes of transport of the container before the transport starts based on International Commercial Terms (InCoTerms). One of the recent developments in freight logistics is the flexibility in the mode of transport, even during the transport. This is called synchromodality. Platform synchromodaliteit

[1]The person or company that operates a (sea) ship, also known as shipping company.
[2]The person or company that consigns a shipment, also known as forwarder or consignor.

(2015) defines synchromodality as *'the optimally flexible and sustainable deployment of different modes of transport in a network under the direction of a logistics service provider, so that the customer (shipper or forwarder) is offered an integrated solution for his (inland) transport'*. This means that the shipper delegates the decision about the mode of transport to the shipping line. Buck Consultant International - Kees Verweij (2015) describes the advantages of synchromodality as follows:

- Increase in opportunities to combine inland waterways, short sea, and rail volumes
- Lower costs, improved service level, and increased sustainability.
- Combination of flexibility (switching between transport modes) and robustness (transport with time tables)
- Less road transport, so less congestion

In this thesis, we conduct research on (synchromodal) container transport scheduling. We regard the intermodal transport company Combi Terminal Twente B.V. (CTT) as a case study for this thesis. CTT acts as a intermodal operator, coordinating, planning, and scheduling the resources, handlings, and shipments from a centralized control tower in Hengelo. CTT is growing and sees opportunities for improvement. This research aims to find opportunities for CTT, but also other logistical companies, to improve synchromodal container transport scheduling.

Section 1.1 describes the problem tackled in this thesis. Section 1.2 discusses the research questions and plan of approach.

1.1 Problem statement

This section introduces the problems at CTT related to this research in Section 1.1.1. Section 1.1.2 presents the research goal. Section 1.1.3 describes the scope of this research.

1.1.1 Problem description

This section introduces four problems at CTT related to synchromodal container transport. We end this section with a short overview of the problems and the research goal that follows from the problems.

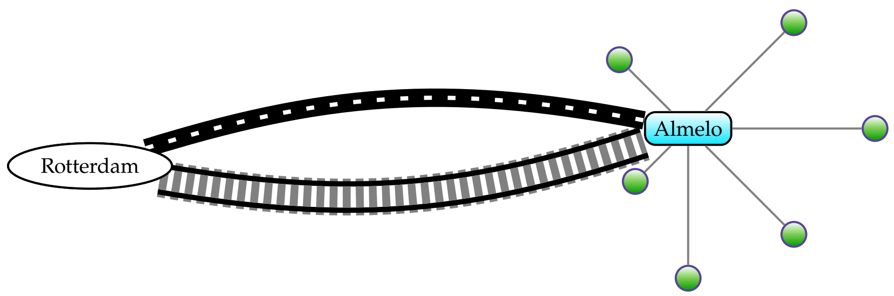


Figure 1.2: Old network of CTT with one terminal and two modalities: train and truck.

CTT started halfway the eighties as an intermodal transport company with one terminal in Almelo with a fixed train connection to the Port of Rotterdam, illustrated in Figure 1.2. The blue rectangle represents an inland terminal of CTT and the green circles CTT's customers. Trucks and trains transported containers between the Port of Rotterdam and customers nearby Twente and Rotterdam.

CTT is growing and now, in 2015, there are four terminals (Hengelo, Rotterdam, Bad Bentheim, and Almelo[3]) and three types of modalities (barge, train, and truck), shown in Figure 1.3.

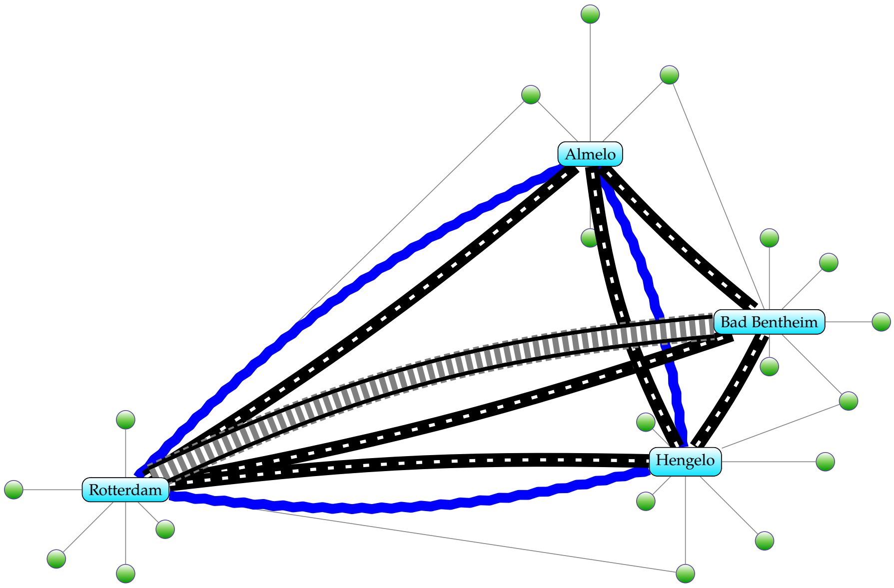


Figure 1.3: Network of CTT in 2015, with four terminals and three modalities.

The railway visualizes transport by train, the blue zigzag line transport by barge, and the straight gray lines and the road represents transport by truck. This the network of CTT, together with the address where the containers are loaded and discharged.

The increase of terminals and modalities gives more possibilities, but also complicates the scheduling process. Moreover, the number of bookings increases from year to year, which makes scheduling even more difficult. This makes the first problem the complexity of the scheduling process due to increasing amount of bookings and modalities.

The second problem is the lack of visibility in the network. To provide synchromodal transport, we need to know what happens in the network with all modalities, to be able to optimize the network at any time. We need to focus on the network, a net-centric view, instead of only one part, a point-centric view. The net-centric view influences the planning and scheduling as well, because it is difficult for planners to think net-centrically and take all consequences of their decisions into account. Therefore, CTT needs a process-based approach instead of the current ad-hoc scheduling approaches. Automation play a big role in establishing this.

The third problem is the change of bookings and resources during the day. Trucks, barges, and trains may have delays, which influence the schedule for the containers. Moreover, during the day customers ask to deliver or pickup containers earlier or later, which influences the schedule as well. This new information is important to take into account for optimal scheduling. An optimal schedule at some point in time might not be optimal a few minutes later, when new

[3]CTT expects the terminal in Almelo to be operational at the end of 2015.

information arrives. The changes in information may results in schedules that are not achievable anymore.

The fourth problem is the lack of direct measurable key performance indicators related to container transport at CTT. For example, the administrative software package Modality keeps track of data regarding departure and arrival times at the terminal, but it is not clear if the containers are at the customer on time. Other performance measures such as costs and sustainability are not directly measurable as well. A database with information about all bookings and containers is available, but in the current format not suitable as a start to measure the performance

The next enumeration summarizes the problems discusses above:

1. The increasing number of possibilities and decisions increase scheduling complexity even more.
2. There is insufficient network visibility to be able to change to net-centric view.
3. Orders and resources change during the day such that schedule is not achievable.
4. Network performance measures as costs, timeliness, and sustainability are difficult to measure.

The overlaying problem of these four sub problems is an information overload for CTT's planners. Information overload occurs, according to Speier, Valacich, and Vessey (1999), 'when the amount of input to a system exceeds its processing capacity. Decision makers have fairly limited cognitive processing capacity. Consequently, when information overload occurs, it is likely that a reduction in decision quality will occur.'

This information is related to containers, requirements of customers, resource availability, and the increasing number of containers and types of resources. These problems lead to the following core problem:

CTT encounters difficulties to schedule container transport on the available modalities in an efficient way due to an information overload on planners.

1.1.2 Research goal

The difficulties with the scheduling of container transport are related to the overload of information. Instead of seeing this as a problem of this information, we should use the information, such that it is of added value. We need to find a way such that the information is presented in such a way that is able to support the decisions for the truck planners while scheduling the containers. Therefore, we formulate the following research goal:

Give support to the truck planners at CTT with scheduling to improve the performance of container transport.

1.1.3 Scope

CTT's network contains sea terminals in Rotterdam and CTT's own inland terminals and customers, connected via barge, train, and truck, with fixed routes, time schedules, and capacities of barges and trains. We focus on the operational level, so we do not take into account strategic decisions such as the location of terminals. The operational level plans and schedules the transport of containers for each of the modalities. This section describes the scope of the thesis.

For simplicity, we assume that the long haul decision is fixed. This means that the modality, departure and arrival time to transport a container from terminal A to terminal B is fixed. This research focuses on the part before and after the long haul: the first and last mile. This is the transport between a terminal and a customer, and vice versa.

The first reason for focusing on trucking, is the high costs of trucking compared to barge or train. Figure 1.4 shows an indication of the costs for trucking only compared to intermodal transport. 'Only truck' indicates that one truck transports the containers from A to B, for example from Rotterdam to Enschede. 'Trucks and barge' indicates that the barge transports the container on the long haul, so for example between the Port of Rotterdam and CTT Hengelo, and the truck transports the container on the first and last mile, so for example between Pernis and the Port of Rotterdam and between CTT Hengelo and Enschede.

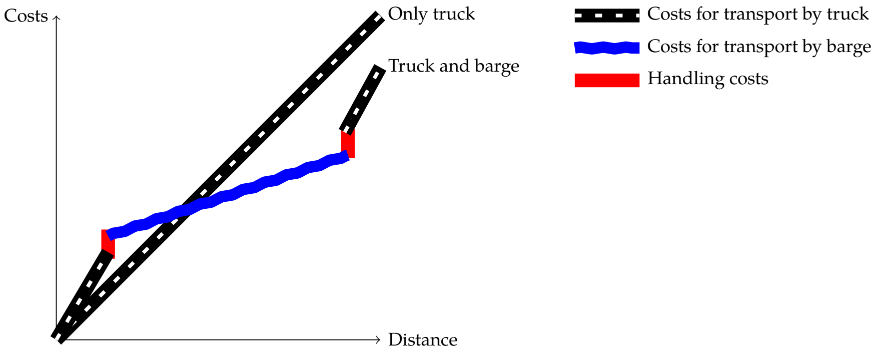


Figure 1.4: Costs of modalities for trucking only and intermodal transport.

We see in Figure 1.4 that trucking is relatively expensive, but it is a fast and flexible mode of transport, because the barge and train need waterways or railways to move and are therefore not always possible. Moreover, the departure of barges and trains depend on more or less fixed schedules. If the distance is longer, a combination with barge (or train) is cheaper.

The second argument for focusing on truck scheduling is the importance to have the containers in time at the customers. Truck scheduling is an important factor in establishing this, because trucks are most flexible of all modes of transport. Note that the scheduling of trucks is dependent on the arrival of barges and trains, and therefore still related to barge and train scheduling.

To summarize, this research focuses on truck scheduling because the of the relatively high costs and the importance to deliver containers in time at the customers. The key performance indicators related to these arguments are costs and timeliness. Since the goal of this research is to improve the performance of container transport, we aim to improve the costs and the timeliness for container transport per truck.

Nevertheless, this thesis describes relevant literature for intermodal and synchromodal transport, and gives suggestions for extending the truck scheduling to the other modalities.

1.2 Research questions and approach

The research goal formulated in the problem statement of Section 1.1.2 is translated into the following main research question:

How can we give decision support to CTT's truck planners to improve the performance of timeliness and costs of container transport per truck?

The sub questions below are formulated to answer the main research question.

1. What is the current situation at CTT?
   (a) What is the current and expected situation in the container transport sector?
   (b) What is the current and expected situation at CTT regarding truck scheduling?
   (c) What are the current scheduling procedures at CTT?
   (d) Which key performance indicators can be used to assess the performance of container transport?
   (e) Which functionalities are needed to support truck planners?

Chapter 2 pays attention to these sub questions. Information will be gathered by observations, documentation, and interviews at CTT. The gathered knowledge helps to place this research in context.

We need some background information on container transport scheduling, before we can set up a model. We review literature about vehicle routing problems related to container transport. Then we need to find a solution method for the problem. As last we review literature on implementing decision support, to gain knowledge before we implement our methodology. The following sub questions help us to structure our review.

2. What is known in academic literature about container transport scheduling?
   (a) What is known about vehicle routing problems and container transport scheduling?
   (b) Which solution method can be used to solve the container transport scheduling problem?
   (c) What is known about implementing decision support?

Chapter 3 answers these questions. With this knowledge, we are able to set up a solution method. Chapter 4 describes the solution method. This method can be used to support the planners. The research questions are as follows:

3. How can container transport scheduling for trucks be supported?
   (a) Which situations should be supported?
   (b) How can the conceptual model be described?
   (c) Which methods can be used to provide the functionalities?

We need to test the solution method to know how the best solutions can be found regarding CTT and the solution method. Chapter 5 describes the experiments which are used to evaluate the solution method. The research question for Chapter 5 and the sub questions are as follows:

4. What are the best settings to improve the performance with using decision support for container transport scheduling?
   (a) What are suitable experiments to test the solution method?
   (b) What are the results in terms of key performance indicators? item How sensitive is the solution to changes in the parameters and situations?

We end this thesis with a discussion in Chapter 6. The appendices contains additional background information.

Chapter 2

Current situation

This chapter describes the current situation of CTT and therefore addresses the first research question 'What is the current situation at CTT?'. Section 2.1 describes the container sector in general. Section 2.2 discusses CTT, the different projects related to this study, the available resources to provide intermodal transport, and the different types of trips. Section 2.3 describes the current scheduling procedures at CTT for barges, trains, and trucks. We describe in Section 2.4 different performance measures to assess the performance of the schedule. Section 2.5 discusses methods to support the planners to improve the performance. Section 2.6 summarizes the conclusions of these sections.

2.1 Container sector

The Netherlands has an important and excellent location in the international logistics network with its Port of Rotterdam as the largest seaport of Europe. It is the gateway to the rest of the continent, with easy accessibility to the sea and the hinterland. In 2014, the throughput in the Port of Rotterdam increased with 1% to 445 million tonnes compared to 2013. The container market segment increased significantly to 12.3 million TEU[1], a difference of 5.8% compared to 2013. The expectation for 2015 is that the throughput increases again with another 1%, with the growth primarily in the container segment (Port of Rotterdam Authority, 2015). This growth in Rotterdam has consequences for the hinterland. The inland terminals in the hinterland connect shippers with the Port of Rotterdam with a barge, train, and/or truck connection. The advantages of barges and trains are that they are more sustainable and cheaper compared to trucks. However, the transport time is higher. For example, a train takes about 4 to 6 hours, a barge between 18 to 22 hours and a truck about 3.5 hours from Twente to Rotterdam, and v.v. Figure 2.1 shows the increasing number of transported containers from year to year. EU-28 is an average of the 28 countries in the European Union.

One of the goals of the European Union (EU) is to decrease the greenhouse emissions with 20% in 2020 (European Commission, 2015). Barges and trains are more and more used for transport of

[1]TEU stands for Twente-foot Equivalent Unit, which is a container of about 6 meters long

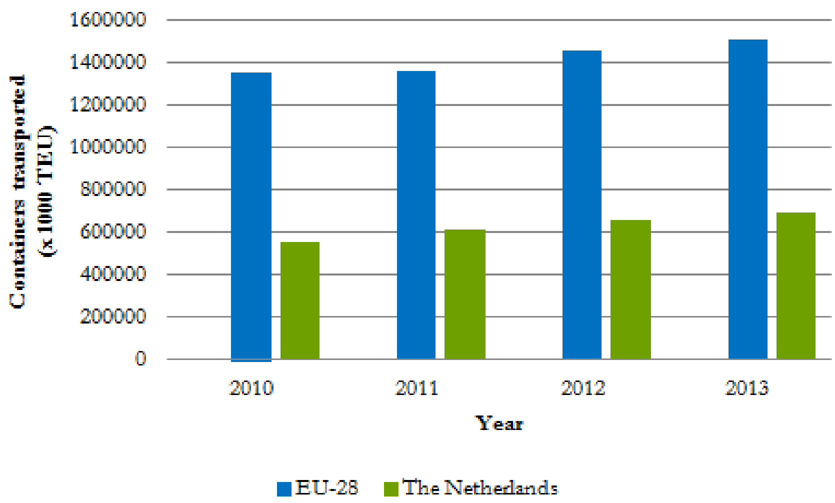


Figure 2.1: Container transport performance of The Netherlands and the 28 European Union Countries (Eurostat, 2015a).

containers instead of trucks, because these modalities are more environmental friendly. Figure 2.2 shows the modal split. We conclude from Figure 2.2 that a modal shift towards environmental friendly transport already takes place, because the percentage of road transport decreased in the period from 2000 to 2012.

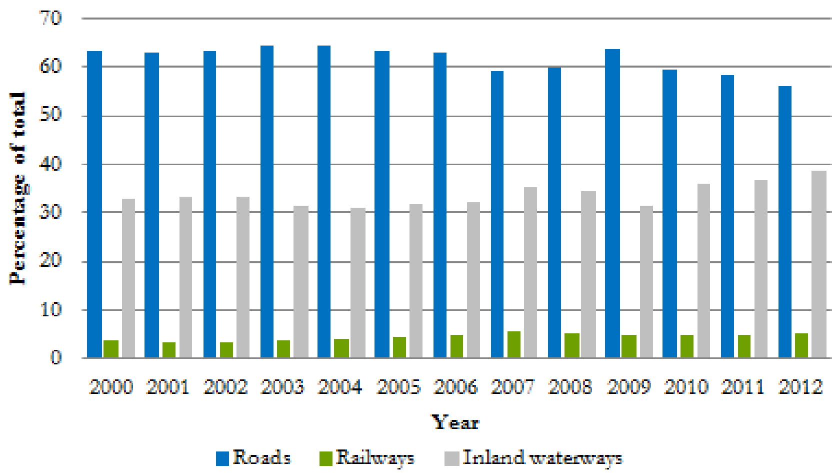


Figure 2.2: Modal split in The Netherlands (Eurostat, 2015b).

Companies with inland terminals need to adjust to the modal shift, but they also need to convince the shippers that this is necessary to be environmental friendly. Flexibility in the mode of transport helps, but we should not forget that timeliness is most important for customers. Before implementing a synchromodal transportation network, the collaboration of shippers and their customers is very important.

CTT has four inland terminals to offer intermodal transport. The next section describes CTT's terminals and bookings in more detail.

2.2 Combi Terminal Twente

Combi Terminal Twente B.V. (CTT) acts as a synchromodal operator, planning and coordinating the resources, handlings, and shipments from a centralized control tower in Hengelo. Besides the main terminal in Hengelo, which is one of the biggest and most modern inland terminals of The Netherlands, CTT owns terminals in Rotterdam, Bad Bentheim, and Almelo. CTT cooperates actively with the Port of Rotterdam. Therefore CTT is also known as 'a little piece of Rotterdam in Twente'. In the same way, the terminal of CTT in Rotterdam is known as 'a little piece of Twente in Rotterdam'. Appendix A presents background information about CTT's terminals and Appendix B presents information about CTT's booking. In the remainder of this section, we discuss CTT in more detail. We start with some background information about CTT.

2.2.1 History and future

CTT started halfway the eighties with a train terminal in Almelo to transport containers between Rotterdam and Twente. In 1997, CTT substituted the train connection in Almelo with a barge connection. Pending on the development of a new, better-equipped terminal in Twente an alternative way to ship via the German Emmerich is made in 1998, because of deficiencies in the Almelo waterway. In 2001, as an initiative of about thirty companies in the Twente region, amongst others AKZO Nobel and Grolsch, CTT started a container terminal in Hengelo. In 2012, the significant volume increase led to an expansion of the terminal from 26,000 to 125,000 square metres. Besides the additional space, an automatic entrance street and enlargement of the quay were made. The increased security methods, such as visual gate, cameras, fences, identification of truck drivers, and Track&Trace, are awarded with a AEO (Authorized Economic Operator) certification.

The volume of CTT's activities is still expanding. In January 2013, CTT started operating a container terminal in Rotterdam, mostly used as a storage area for containers, but also as a hub for the terminals in Rotterdam and to be connected by train to the terminal in Bad Bentheim. Halfway 2015, the terminal in Almelo will be operational. A new warehouse in Hengelo gives the opportunity for customers to unload and palletize goods and then store them in the warehouse. Enough space is available to build two extra warehouses.

In the future, CTT plans to expand to other regions such as Poland and Scandinavia. CTT is a regional company, but wants to connect with other regions in The Netherlands and in Europe. The use of barges or trains for the long haul becomes more and more important. A change from point-centric to net-centric view is important for the expansion of intermodal transport.

The logistical cluster of inland terminals of CTT is not the only cluster in The Netherlands. MCS (North of The Netherlands), BCTN (South of the Netherlands), and CTT (East of the Netherlands) work together. For example, the companies direct customers to the other companies if a booking cannot be fulfilled by themselves. In the future it is possible that the clusters are connected, to balance the empty containers of shipping lines. Trips from the clusters to Rotterdam replace trips between the clusters, to balance the difference for import and export containers.

2.2.2 Related projects to synchromodality

Synchromodality is a relatively new subject and is studied in various recent projects and organizations, such as Port of Twente, Synchromodal-IT, and SIEEG. This section explains these further.

Port of Twente[2]
Entrepreneurs, government, education institutions, and research institutions all work together in the Port of Twente to strengthen the economy around the Twente region by creating more jobs in the logistics sector.

The Port of Twente has the following goals:

1. In 2020 a top 3 position for logistics regions in the Netherlands.
2. More and smarter logistics.
3. Port of Twente established as authority for logistics in Twente.

Synchromodal transport is one of the examples included in the second goal.

Synchromodal-IT[3]
The project's main objective is: "*to enable efficient, reliable, and sustainable delivery of logistic services and strengthen the Dutch logistic sector through (i) the design of an synchromodal logistic network model and integrated service platform and (ii) the development of related planning and scheduling policies, and of decision support through serious gaming.*" The University of Twente and CTT are members of this consortium. The results of this research can be used in other projects of Synchromodal-IT.

SIEEG
One of the problems encountered in this thesis is the change from a point-centric to a net-centric view. This requires increased visibility of the network, which is provided within the SIEEG project: "*The SIEEG functionality consists of a web service which gives insight into relevant data regarding the handling and transportation of goods 24/7*[4]." Sensors in the network, for example at the inland terminal of CTT in Hengelo, give this additional data at multiple points in the network to provide increased visibility. This information can be used in the model of this thesis to track the locations of the resources and the containers.

2.2.3 Available resources

CTT does not own modalities, but hires trucks, barges, and a train. In this section we describe the different resources of CTT. Bolk Transport B.V. is CTT's partner and provides about 30 trucks for the transport of containers for CTT, and also a warehouse and a workshop for trucks. In addition, about 15 charters can be used. A charter is not allied with Bolk or CTT, but is paid per trip. For transport on inland waterways, CTT has four fixed barges with a capacity of 104 TEU

[2]http://www.portoftwente.com/
[3]http://www.Synchromodal-IT.nl
[4]Secure Information Exchange Extended Gate: http://www.dinalog.nl/en/projects/demo_projects/sieeg/

to ensure daily trips between Rotterdam and Hengelo. The train between Bad Bentheim and Rotterdam has a shared capacity with Euroterminal Coevorden. The train has an even 46 TEU split for CTT Bad Bentheim and for Coevorden, and departs three times per week.

2.2.4 Types of trips of containers

This section describes the different trips that CTT offers and the relation with shippers and shipping lines. We end the section with an overview of the types of trips at CTT.

Shippers are persons or companies that need to transport a container, for example production companies. A shipping line is the owner of a ship and they may also have a fleet of own containers, for example Hapag Lloyd or Maersk. When the demand is high, shipping lines can lease containers at container leasing companies. Shippers agree with shipping lines upon the transport overseas. Inland terminals are used as hubs to consolidate flows of containers from the hinterland to the sea ports, where the shipping lines take care of the further transport. CTT offers intermodal transport between the sea port in Rotterdam and the shipper. Shippers agree with CTT upon the inland transport, taking into account the agreements concerning the export or import in Rotterdam.

CTT offers different types of trips for containers. Barges, trains, and trucks transport the containers between Rotterdam, inland terminals, and the loading/discharge address (LD address) of the shipper. If we say Rotterdam, we mean one of the terminals in Rotterdam. We start with explaining the round trip, in which a combination of barge, train, and truck visits all locations for a container. The single and depot trip and trucking only are deduced from the round trip. For simplicity, we assume that barges and trains transport containers between Rotterdam and inland terminals, and the trucks between inland terminals and LD addresses. In practical situations where there is not much time, trucks can also transport containers between Rotterdam and LD address or inland terminal.

Round trip

Figure 2.3 shows a round trip, which means that a container is picked up and delivered in the Port of Rotterdam. It depends on the load of the container if the trip is an export round trip, import round trip or both. At an import round trip, the container is loaded in Rotterdam, usually because a sea ship transported the container to Rotterdam. The loaded container departs by barge or train from Rotterdam to an inland terminal. A truck transports the loaded container from the inland terminal to the customer. It depends on the agreements if the truck and truck driver wait at the customer or that the truck driver decouples the chassis with the container. When the customer finishes discharging, the same or a different truck transports the empty container to the inland terminal. From there, a barge or train transports the empty container back to Rotterdam. This container is needed for another booking, or is stored at an depot with empty containers.

An export round trip follows the same route, but in the first part the container is empty and the second part, the container is loaded because the container is not discharged, but loaded at the

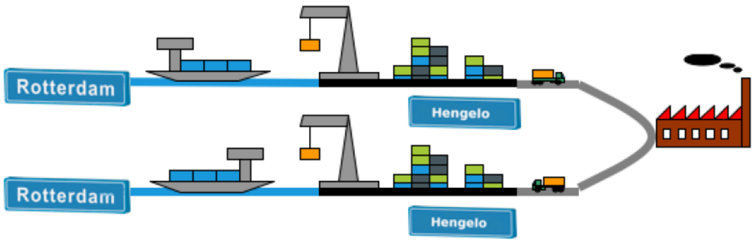


Figure 2.3: Round trip. The container starts in the 'upper Rotterdam', and follows the route clockwise to the 'bottom Rotterdam'.

customer. A combination of import and export round trip is also possible. This is the case when the customer imports and exports goods.

Single trip

The difference between a single trip and a round trip is that in a single trip, the container is delivered or picked up at an inland terminal instead of Rotterdam. Figure 2.4 shows an import single trip. A single trip means that a barge or train picks up the loaded container in Rotterdam

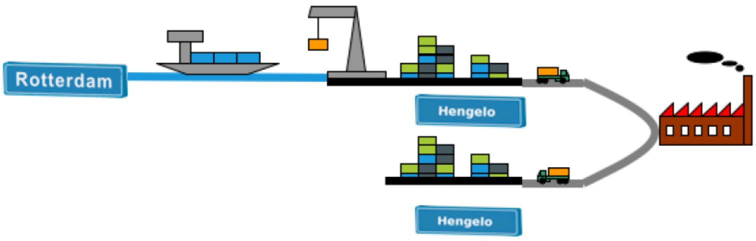


Figure 2.4: Import single trip.

and transport to the inland terminal. A truck continues the trip to the discharge address and finally, also by truck, to the depot at the inland terminal to be stored. This is only possible if the owner of the container and the inland terminal agreed upon this. Export single trips balance the number of containers at the inland terminal, because empty containers from the depot are transported to the loading address. A truck transports the loaded container from the loading address to the inland terminal, where a barge or train transports the container to Rotterdam for export.

Depot trip

A depot trip is only the part between inland terminal and Rotterdam. In this case, customers pick up or deliver the container itself to the inland terminal, or a shipping line company repositions empty containers. Figure 2.5 shows an import depot trip.

Trucking

Transport of the container is only executed by trucks. The container goes directly from origin to destination, without a visit to an inland terminal. Companies choose trucking when it is impossible to transport by barge or train, for example due to time restrictions.

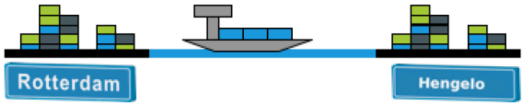


Figure 2.5: Import depot trip from Rotterdam to the inland terminal in Hengelo.

2.2.5 Transport of containers per truck

This research focuses on the trucking part. Section 2.2.4 described the different types of trips. However, only part of a trip is executed by truck. This section describes the different trips relevant for truck scheduling and defines jobs.

A container job consists of multiple moves. We do not distinguish loaded and empty containers on a trip from here on, because the route for a container is fixed. This means that when a move for a container is done, the truck never has a container. In general, the moves from the inland terminal to the LD address are trucking moves and the moves between inland terminals and sea terminals (long haul) are barge or train moves. However, in case of a hurry, a truck can transport a container from the sea terminal directly to the LD address, or vice versa. Each move corresponds to a specific date, the transport date. It is possible to have multiple moves on one transport date, which means that the container should be transported multiple times per day. The following enumeration specifies the different transport dates.

- Import trucking date. This is the date at which the container should be picked up at a sea terminal or empty depot and transported to the LD address.
- Loading/discharge date. This is the date at which the container should be loaded or discharged, so the date at which the container should be at the customer.
- Couple date. This is the date at which a decoupled chassis and container can be picked up and coupled to a (different) truck. The couple date is the same as the loading/discharge date if decoupling is not allowed. In this case, the trucks waits at the LD address until the service for the container finishes.
- Export trucking date. This is the date at which the container should be transported from the LD address to a sea terminal or empty depot.

A move is a transport between two locations and a job is a combination of moves. Table 2.1 describes the possible locations for a move.

Table 2.1: Locations of jobs

Description	Abbreviation
Sea terminal for import	S_1
Inland terminal 1	I_1
LD address	L
Inland terminal 2	I_2
Sea terminal for export	S_2

Table 2.2 shows seven types of jobs. These are inherited from four main type of jobs, namely delivery (or Gate OUT), pick up (or Gate IN), import, and export jobs. A special case is where

decoupling is not allowed at the customer. The delivery and pickup move need to be performed by the same truck. This is defines as a ‘both’ move. Furthermore, the import and export moves are also possible to or from an inland terminal, when there is too less time to transport the container by barge or train.

Table 2.2: Different jobs and their visits

	From	Via	To
Import job 1 (IM_1)	S_1		I_1
Import job 2 (IM_2)	S_1		L
Delivery job (D)	I_1		L
Both (B)	I_1	L	I_2
Pick up job (P)	L		I_2
Export job 1 (EX_1)	L		S_2
Export job 2 (EX_2)	I_2		S_2

2.3 Current scheduling procedures at CTT

This section describes the current scheduling procedures for barges, trains, and trucks at CTT. Appendix C gives the flowcharts related to the bookings and scheduling of containers.

New bookings of containers arrive at the Customer Service department. Containers have a unique container number which is one piece of information needed to complete a booking. Other information needed is:

- Customer
- Shipping company
- Container number(s)
- Container type(s)
- Pick-up reference
- Pick-up and delivery location (LD address)
- Pick-up date and time

The administrative software package Modality is used at CTT for information about the bookings, in which, amongst others, the planners and customer service employees work. Before a planner schedules a container, the information about the exact dimensions and weight of the container are needed too.

The planning (and scheduling) department consists of barge planners, train planners, and truck planners. The scheduling of containers follows a sequential approach. First the barges and trains are scheduled, then the trucking to the sea port, and then the regional trucking (around Twente). Nevertheless, truck planners cannot schedule a container if it is delayed with the barge or train, and vice versa. Each of the individual schedules may be optimal, but the combined schedule over all transport modes might not be optimal. The next sub sections explain the separate scheduling procedures for the three modalities in more detail.

Barge scheduling

Barge planners allocate containers to barges such that their capacity, in most cases 2 layers (in total 104 TEU) or 3 layers (156 TEU), is used as much as possible. The captain of the barge takes care of the location of the containers in the barge, that is, for an equal weight distribution and a logical load and unload sequence. Import and export documents should be conform the regulations of customs before transportation. If the customers do not deliver the documents correctly, the container has to wait for the next barge or train. If that is not an option, for example because of time restrictions, the container has to be transported by truck against additional costs. It depends on the contract if CTT has to pay, or the shipper.

The most important constraints for the allocation of container to barges are:

- Departure and arrival time of barge
- Closing time for containers at terminal
- Capacity of barge (in weight and TEU)
- Weight and size of containers
- Demurrage and detention. Demurrage starts when the free period of storing a container at a sea terminal is past. Detention comes when thee free days for picking up a container are past.

Train scheduling

The schedule for trains is more or less fixed. Three times a week, a train drives between Malmö and Rotterdam via Bad Bentheim. CTT shares this train with Euroterminal Coevorden. The schedule is made such that this train with a capacity of 46 TEU for CTT is utilized as much as possible, taking into account the sizes and weights of the containers and capacity of waggons.

The most important constraints for scheduling trains are:

- Departure and arrival time of train
- Closing time for containers at terminal
- Capacity of train (in weight and TEU)
- Weight and size of containers

Truck scheduling for the first and last mile

Trucks transport the containers between the terminals and the LD addresses. The distances are typically short compared to transport by barge and train. The containers that need to be transported on the current day or at the begin of the next day are selected in Modality in the start screen. Modality also provides an overview of the decoupled containers at the customers. The truck planner selects for each move the truck and the trip number of the truck. A move is defined as a transport between two locations. The location is a sea terminal, inland terminal, or a LD addresses. The truck driver receives a message with its next job(s). The truck planner has to take into account the constraints below.

The most important constraints for scheduling trucks are:

- Loading/discharge time at customer or closing time at terminal
- Time windows of customers
- Drive and working time of truck drivers and capabilities
- Availability of truck and chassis
- Weight and size of containers

Truck scheduling is always dependent on the schedules of barges and trains, because it is the most flexible modality. Decisions for barge and train schedules influence the truck schedule. It is clear that the choice of modality on the long haul affects the truck schedule, but it is hard to make exactly clear what the consequences are and how this should be improved. With this research, we want to give insight in possibilities to improve performance indicators, for example timeliness, with synchromodal scheduling.

2.4 Performance indicators

This section describes the key performance indicators that are relevant for container transport and therefore answers the research question 'Which key performance indicators can be used to assess the performance of container transport?'.

The key performance indicators are deduced from interviews at CTT. The indicators can be divided into indicators relevant for customers, but also for transport companies such as CTT. The first KPIs are relevant for customers, and the last KPIs may be interesting for transport companies.

Relevant key performance indicators for customers

Lateness and service are key performance indicators for customers.

1. Not in time

Several containers have a strict LD time. This means that the customers needs the container at that time. The containers that are too late are taken into account for the indicator 'Not in time'. Not all LD addresses are very strict in the LD time, and therefore these containers are not taken into account for this indicator.

2. Time too late

The time that containers are too late may differ from 1 minutes to 6 hours. In the indicator above, this difference is not take into account.

3. Time not in time window

Lateness indicates the total time too late of containers are delivered outside the soft time window (TW). Customers expect that containers are delivered at the loading/discharge time, but we assume that there is a certain time period in which the container is still in time, for example, 20 minutes before and after the agreed loading/discharge time. If the container is delivered outside this time window, this is included in this key performance indicator.

4. Not in time window

Not in time window (TW) is defined as the total number of containers that are delivered outside the soft time window. This key performance indicator does not distinguish if the container is 2 minutes too late or 2 hours.

Relevant key performance indicators for transport companies

The following indicators are relevant for transport companies.

5. Total number of trucks

Less trucks means less fixed costs for the resources, but limits the total number of jobs that can be performed and therefore also influences the number of containers which are in time at the customer. We need to consider the importance of both timeliness and number of trucks, because they influence the customer satisfaction and (fixed) costs.

6. Travel time

Optimizing the travel time results in less costs, because we need less trucks and trucks drivers, and also less fuel costs. Of course, travel time should not decrease by driving faster, but by combining delivery and pick up jobs is a smart way for example.

7. Waiting time

Trucks drivers have to wait if the container is delivered too early at the loading/discharge address. This time is expensive for transport companies, because also other jobs can be performed in this time period. Nevertheless, if the container is in time, but the customer at the loading/discharge time is not yet able to load or discharge the container, costs are charged to the customer.

8. Number of detours

A detour is a move from one job to another job, if the arrival location is different from the departure location. A truck does not transport a container at a detour. These detours are important for CTT, because detours can be merged and this saves costs for the transport company.

9. Total time of detours

The total time of detours is the total travel time of trucks that is spend on detours.

Besides these key performance indicators, costs and CO_2 are good indicators, but these are difficult to measure. However, to get an indication, we assume that less travel time results in less costs and less CO_2 emission.

For CTT it holds that the customers is most important, and therefore we take lateness and service as the most important key performance indicators.

Current performance CTT

A group of three Business and IT (BIT) bachelor students performed a research of four months on the performances of CTT's container transport (Bruining, van Aggelen, & Muller, 2015). They used the database of Modality to measure performances related to timeliness at customers with trucks. The result is an application that can be used internally at CTT to see how many containers are too late at the customers, but also the expected situation regarding containers that are expected to be too late at the loading/discharge address.

The application is not yet able to measure travel times using GPS coordinates, because the GPS coordinates are not reliable. To measure the travel times, they used the following formula for the speed:

$$\text{speed} = \min\{40 + 1.45(\text{distance in km} - 15), 65\} \tag{2.1}$$

The travel time is then calculated by dividing the distance by the speed.

The results of this research can be found at an internally reachable IP-address, because of confidentiality.

2.5 Functionalities DSS

The goal of this research is to give decision support to CTT's truck planners to improve the performance of container transport scheduling. The enumeration below shows features to support the truck planners. Section 4.3 describes the methodologies for these features.

1. Scheduling on latest departure time instead of arrival time

The current system knows at which time a container should be at its LD address. However, the system does not give the corresponding latest departure time. Experienced truck planners know the travel time between two locations, but new truck planners learn this using Google Maps for example. Implementing a functionality which calculates the latest possible departure time supports the truck planners with the allocation of container to trucks. Moreover, sorting the containers on increasing latest departure time helps to prioritize the containers.

2. Number of trucks needed

The truck schedule depends on the number of trucks available on a day. However, the number of trucks depends on the expected number of containers and travel times for a day. When demand is low, it is not necessary to use all trucks, and in this case, no additional charters are hired. Nevertheless, resources as trucks are limited in short term. In the long term, a company may decide to hire or buy additional trucks.

3. Offline scheduling

Before a day starts, it is not known how the day proceeds. An offline schedule helps the truck planner to give an initial schedule for that day with the information about resources and demand at that moment. If the offline schedule already has bottlenecks, for example with getting containers in time at customers, truck planners can anticipate on this and inform customers about this.

4. Online scheduling

With online scheduling, the offline schedule is updated with the newest information, for example, location of trucks and changes in resources and demand. The online schedule provides information about the next container to depart for example.

5. Synchromodal scheduling

This research is focused on trucks. However, barge and train scheduling depends on truck scheduling, and vice versa. Suggestions about the choice between barge and train are helpful to improve the whole network.

2.6 Conclusions on current situation

This chapter answered the first research question 'What is the current situation at CTT?'. The enumeration below summarizes the findings based on the sub question belonging to the first research question.

- Section 2.1 describes the container transport sector. The container sector is growing in the last few years, which was 12.3 million TEU in 2014. Port of Rotterdam Authority (2015) expects that this growth continues in 2015. The transport of containers by trucks should shift to transport by train and barge, to decrease the greenhouse emissions with 20% in 2020.
- Section 2.2 described Combi Terminal Twente (CTT). CTT, also known as 'a little piece of Rotterdam in Twente', experiences the growth as well and seeks to possibilities to improve synchromodal transport. CTT is involved in different projects related to synchromodality and has possibilities to improve synchromodality because three types of modalities are available, namely barge, train, and truck. CTT described itself as a synchromodal operator, planning and coordinating the resources, handlings, and shipments from a centralized control tower in Hengelo. CTT offers different trips with different types of container by barge, train, and/or truck.
- Section 2.3 described CTT's scheduling procedures. CTT has different planners for the barges, trains, and trucks. The schedules depend on each other, but the dependencies are not always clear. This means that well-intentioned changes for one modality affect the other schedules, which could lead to a total performance worse than the current situation.
- Section 2.4 described the key performance indicators (KPIs) that are relevant for customers and transport companies such as CTT. The KPIs are:

1. Not in time
2. Time too late
3. Not in TW
4. Time not in TW
5. Number of trucks
6. Travel time
7. Waiting time
8. Number of detours
9. Detour time

A group of three Business and IT students of the University of Twente performed a study on the performance of CTT related to timeliness and waiting times. The results of that study can be used to steer the scheduling of container transport at CTT.

- Section 2.5 described functionalities that will support the truck planners of CTT for the scheduling of containers and trucks. The functionalities are:

  1. Scheduling on departure time
  2. Calculate number of trucks needed
  3. Provide an initial schedule for a day
  4. Update schedule during the day when changes in resources and demand occur
  5. Suggestions about using barge instead of train, or vice versa.

Chapter 3

Literature review

This chapter describes the relevant literature related to scheduling synchromodal transport. This review answers the second research question 'What is known in academic literature about container transport scheduling?'.

Container transport scheduling involves the real-time allocation of containers to modalities in a network. This is an example of a Vehicle Routing Problem (VRP), described as *'a whole class of problems involving the visiting of 'customers' by 'vehicles'* (Christofides, 1976).' In this thesis, we use the VRP as a basis to describe and solve the research problem described in Section 1.1.

This chapter continues with a description of Vehicle Routing Problems (VRPs) in Section 3.1. Section 3.2 describes solution methods for VRPs. The goal of this research is to support the truck planners by taking decisions about scheduling. Section 3.3 discusses important aspects to know before implementing a system that support the decisions.

3.1 Vehicle routing problems

This section answers the sub question 'What is known about vehicle routing problems and container transport scheduling?'.

The section starts with a description of a VRP and is followed by different extensions of the basic VRP and a scheme to classify VRPs.

3.1.1 Description of vehicle routing problems

The definition of a vehicle routing problem is *'the assignment of vehicles to jobs (the pickup and delivery of containers) in an appropriate order such that time and vehicle restrictions are not exceeded'* (Yang, Jaillet, & Mahmassani, 2004).

Equations 3.1 to 3.7 give the standard mathematical formulation for a VRP, without time and capacity restrictions. x_{ij} is equal to 1 if a vehicle drives from customer i to j, and equal to 0 if not. c_{ij} are the costs to from i to j. V is the set of all locations and K is the number of vehicles. S is a sub set of V, so a sub set of customers.

$$\min \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij} \tag{3.1}$$

$$\text{subject to} \sum_{i \in V} x_{ij} = 1 \qquad \forall j \in V \setminus \{0\} \tag{3.2}$$

$$\sum_{j \in V} x_{ij} = 1 \qquad \forall i \in V \setminus \{0\} \tag{3.3}$$

$$\sum_{i \in V} x_{i0} = K \tag{3.4}$$

$$\sum_{j \in V} x_{0j} = K \tag{3.5}$$

$$\sum_{i \notin S} \sum_{j \in S} x_{ij} \qquad \forall S \subseteq V \setminus \{0\}, S \neq \emptyset \tag{3.6}$$

$$x_{ij} \in \{0, 1\} \qquad \forall i, j \in V \tag{3.7}$$

Equation 3.1 is the objective function and aims to minimize the total costs for all routes. Equation 3.2 and 3.3 ensure that each customer is served by exactly one vehicle. Equation 3.4 and 3.5 ensure that the same number of vehicles is leaving and entering the depot, and that this exactly equal to K. Equation 3.6 ensures that there are no routes disconnected from the depot. Equation 3.7 restricts the decision variable x_{ij} to be 0 or 1.

Figure 3.1 shows an example of a VRP. On the left hand side we the customers in the network and the links between the customers. On the right hand side, we see a solution with the routes between the customers, where each customer is visited exactly once with in total 5 trucks.

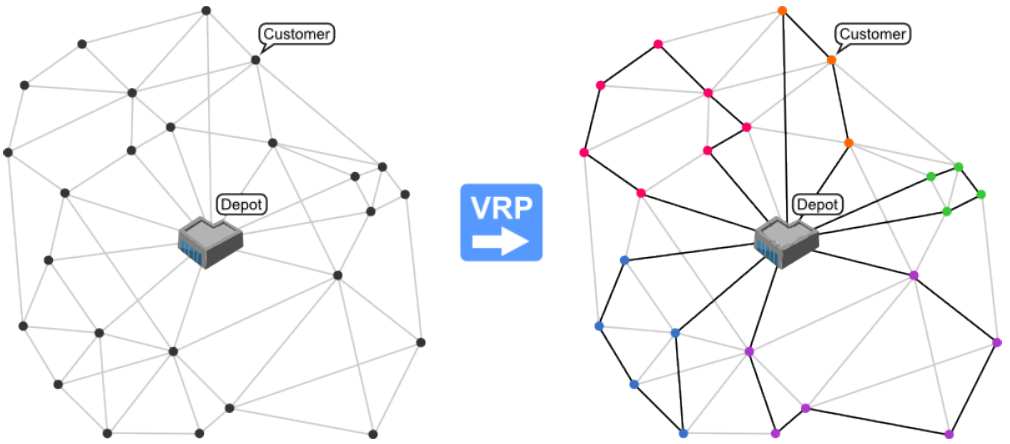


Figure 3.1: Example of vehicle routing problem (NEO, 2015)

3.1.2 Different types of vehicle routing problems

The VRP mentioned above, is a classical VRP without additional restrictions for customers or vehicle. An overview of other types is given below. citeToth2001VRP,de2014vehicle.

- CVRP: Capacitated VRP or Classical VRP. The trucks need to fulfill the (different) demands of the customers. There is one depot and all vehicles have the same capacity and each one travels exactly one route. Vehicles start and end at the depot and visit each of the customers exactly once. Objective is commonly to minimize travel time or distance.
- HFVRP: Heterogeneous Fleet VRP. The capacity may differ per vehicle.
- VRPTW: VRP with Time Windows. Deliveries are only allowed in a certain time interval at the customer. Restrictions can be hard or soft, meaning that the condition is strict or that a penalty must be paid outside the time interval.
- VRPPD: VRP with Pickup and Delivery. Goods have to be picked up at a customer and delivered to another location by the same vehicle in the same route.
- VRPB: VRP with Backhauls. This problem is related to VRPPD. A route contains pickup and deliveries, but not necessarily from the same customer. The destination location is in most cases the depot itself.
- MDVRP: Multi-Depot VRP. Multiple depots spread out between customers. Vehicles may start and end at a different depot.
- DVRP/VRSP: Dynamic VRP or Vehicle Rescheduling Problem (Li, Mirchandani, & Borenstein, 2007). The problem concerns the reassignment of vehicles to routes when jobs are added or changed in the current situation, or when there are problems with the vehicles, with minimal operation and delay costs.
- Intermodal VRP. Multiple modalities, for example, barge, train, and truck, transport the container from pick-up location to the destination.
- Synchromodal VRP. The scheduling of a route for a container at multiple modalities where information about orders and resources is continuously synchronized. In this way, the best, for example, cheapest, fastest, or most sustainable, mode of transport is chosen.

The list with VRPs above only mention some aspects of many real-life applications (Goel & Gruhn, 2008). However, the general vehicle routing problem of Goel and Gruhn covers many aspects:

- Time window restrictions
- Heterogeneous vehicle fleet with different travel times
- Travel costs and capacity
- Multi-dimensional capacity constraints
- Order/vehicle compatibility constraints
- Orders with multiple pickup, delivery and service locations
- Different start and end locations for vehicles
- Route restrictions for vehicles

Goel and Gruhn describe also a mathematical formulation with these restrictions. Iterative improvement approaches based on changing neighbourhood structures during the search are the used solution methods. The approach assumes that not all orders have to be accepted, but can be forced by setting a high reward for the orders.

Section 3.2 describes more solution methods related to VRPs. But first, we describe literature about intermodal and synchromodal scheduling.

Intermodal and synchromodal transport scheduling

Intermodal freight transport started to appear in analytical publications since 1990 (Bontekoning, Macharis, & Trip, 2004). Intermodal freight transport decisions problems need models to help in the application of operations research techniques, but research is still limited in this field. We refer to Macharis and Bontekoning (2004), Macharis et al. (2011), Caris, Macharis, and Janssens (2013), Steadieseifi, Dellaert, Nuijten, Van Woensel, and Raoufi (2014) and Bontekoning et al. (2004) for recent review literature on intermodal transport.

(Braekers, Caris, & Janssens, 2013) focuses on the drayage operations of full truckload vehicle routing problems. The model assumes that the origin or the destination of the empty containers are not predefined. The problem is formulated as an asymmetric Traveling Salesman Problem with Time Windows (am-TSPTW). The article does not describe the combination of two modalities, but gives an approach for the first and last mile.

International intermodal routing is difficult for three reasons: multiple objectives, scheduled transportation modes and demanded delivery times and transportation economies of scale. (Chang, 2008) encompass these three characteristics in a mathematical model and solve the problem with a heuristic. The difference with national intermodal logistics is that international logistics also uses air and ocean as modalities, compared to the truck and rail combinations with truck.

International intermodal freight transport is discussed in (Cho, Kim, Choi, Park, & Kang, 2007; Cho, Kim, & Choi, 2012) as well. The problem is presented as a Weighted Constrained Shortest Path Problem and solved by first setting a feasible area. After that, by applying the Label Setting algorithm, a type of Dynamic Programming, the problem can be solved with two objective functions simultaneously. First and last mile decisions are not taken into account in this article.

Limited literature is available on on synchromodal transport. We refer to (Harris, Wang, & Wang, 2015), P. M. Singh (2014) and P. Singh and Van Sinderen (2015) for more information on synchromodal transport.

3.1.3 Classification of vehicle routing problems

A classification helps to characterize the current situation at CTT to gain a clear and complete view of the problem. It is a first step towards the development of a model (Desrochers, Lenstra, & Savelsbergh, 1990) and to see what type of VRP this problem is related to.

Desrochers et al. propose a classification scheme for vehicle routing and scheduling problems and illustrate the scheme on a number of examples from literature. The classification scheme specifies the type of addresses, vehicles, problem characteristics, and objectives. These four fields are subdivided and indicated with short notations. Appendix D contains the complete scheme. This classification is used for static and deterministic situations. Eksioglu, Vural, and Reisman (2009) proposes a taxonomy that also incorporates stochastic and dynamic VRPs and other uncommon situations.

We classify the situation at CTT with the classification scheme of Desrochers et al., because we model the situation as static and deterministic. This means that we know all details of containers and trucks and these will not change. The classification of the situation at CTT is as follows:

$$l, TASK, \pm, tw_j \mid , m, cap_i, ded, tw_i, dur_i \mid \Delta, /, full, \geq 1R/V, \geq 1D/R, prec, DA, AV \mid SUM$$

This means that we have for the addresses:

- Multiple depots
- Task routing with mixed deliveries and collections and deterministic demand
- Single time windows

For the vehicles, the following classification holds:

- At most β_2 vehicles can be used, with β_2 dependent on the problem instance
- Vehicles have different capacities
- Vehicles have dedicated compartments, which means that compartments can store only one type of goods
- Different time windows for vehicles
- Different bounds on route duration

The problem characteristics are classified as:

- Network has costs satisfying the triangle inequality in an undirected network
- A priori splitting of demand (not all containers for one day delivered at the same time by one truck), with full loads, with more than one route per truck allowed and truck do not necessarily have to end at same depot as where it started
- There are precedence constraints, depot-address restrictions, and no address-address restrictions
- There are no depot-vehicle restrictions, but there are address-vehicle restrictions
- There are no vehicle-vehicle restrictions (two or more vehicles must exchange loads or assist each other)

Related to the objective, we have the following aspects:

- Minimize the sum of the cost function values, but the type of costs varies per problem instance

All these aspects cannot be translated to one type of VRP. The problem at CTT is a combination of many VRPs, which are:

- Vehicles with fixed capacities
- Heterogeneous fleet
- Time windows at customers, terminals and for resources
- Pick up and delivery
- Release and due dates
- Multi-depot
- Full truck load

3.1.4 Conclusions on vehicle routing problems

This section answered the sub question: 'What is a vehicle routing problem and what types of vehicle routing problems exist?' We showed a formulation of the basic VRP and know various types of VRP, with amongst others, VRPs with time windows and pick up and delivery. We classified the problem at CTT according the scheme of Desrochers et al. We see that the problem at CTT is a combination of almost all types of VRPs, which make it a hard problem. We use this knowledge to find a solution method, which is further described in Section 3.2.

3.2 Solution method

This section addresses the research question 'Which solution method can be used to solve the container transport scheduling problem?'. In Section 3.1 we described the problem as a VRP, so we look for solution methods for VRPs to find a suitable methodology for container transport scheduling problem.

Appendix E presents a list with solution methods for VRPs. The solution methods can be distinguished in exact methods and heuristics. A heuristic is an approach to solve the problem that employs a practical methodology, but does not guarantee to find the optimal solution. Exact methods are able to solve the problem to optimality. This section starts with describing how we can describe the problem to solve the problem to optimality.

Integer linear programming is a exact mathematical optimization method in which linear relationships are set as restrictions in order to achieve the best outcome. Dantzig, Orden, Wolfe, et al. (1955) described the first linear program, which is the generalized simplex method. The standard formulation of a linear program is as follows:

$$\begin{aligned} \text{minimize} \quad & \mathbf{c}^T\mathbf{x} \\ \text{subject to} \quad & A\mathbf{x} \leq \mathbf{b} \\ \text{and} \quad & \mathbf{x} \in \{0, 1\} \end{aligned}$$

The vector x represents the set with decision variables. The vector c represents costs. The second equation represents all constraints. The last equation ensures that the decision variables are non-negative.

Lenstra and Kan (1981) proved that the solving a VRP with side-constraints is NP-hard, so only small instances can be solved to optimality. Heuristics are appropriate for realistic problems and are used to give good solutions in an acceptable amount of time, but not always the optimal solution. It is not always necessary to solve the problem to optimality, especially if this saves a lot of time. Solutions of heuristics can be compared to the lower bound of ILP or LP solution for small instances of the problem, to get an indication of the difference in objective value between the optimal and the heuristic's solution.

The list with solution methods in Appendix E describes heuristics which are able to find local optima, for example, steepest descent, but also heuristics which can escape from a local optimum, for example, tabu search and simulated annealing. Tabu search chooses from all its neighbors the best solution that is not yet in the tabu-list, even if this is worse than the current solution. The algorithm stops for example after a fixed number of iterations or number of iterations without improvement. Simulated annealing accepts a worse neighbor solution with a certain probability. So simulated annealing evaluates one neighbor at a time and tabu search many. Since tabu-searches amongst all its neighbors, this is very time-consuming. Simulated annealing is therefore used as solution methodology. Section 3.2.1 describes the details of simulated annealing, but first, the idea of simulated annealing is explained.

Figure 3.2 shows the performance, for example costs, for an one-dimensional setting x. Suppose that we need to find the best performance. When we start at the point at the red arrow in the figure on the left, we are looking for points nearby that are higher. If we go to the right, we find better solutions. At some point, it is not possible to find better solutions. We found a local optimum and are not able to say if this is the global optimum, because we do not know the global optimum. We end up with the solutions settings indicated with the red arrow on the right hand side.

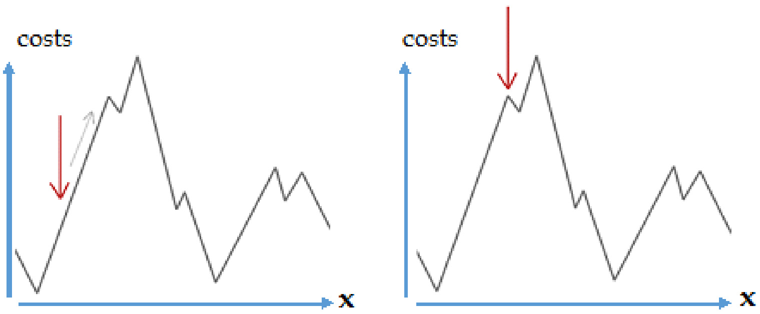


Figure 3.2: Local search method

Simulated annealing is able to jump out local optima. This means also that we sometimes accept worse solutions, to find a better solution later on. In the beginning, the probability of accepting worse solutions is higher, but when time goes by, only better solutions are accepted. In this way, simulated annealing gets closer to the global optimum, but will not always find this.

3.2.1 Simulated annealing

This section describes the two phases and the parameters of simulated annealing. The solution method for our vehicle routing problem uses this information.

The simulated annealing heuristic finds it origins in the physical annealing process of solids. Kirkpatrick, Gelatt, Vecchi, et al. (1983) and Cerny (1985) both used this process as a solution method for combinatorial problems. The idea is that solutions leading to a worse objective value compared to the current solution, should not be denied in all cases, but are sometimes accepted to find a better local optimum, or even the global optimum.

Simulated annealing consists of two phases. The first phase constructs a random, but feasible, initial solution, which is a feasible truck schedule. The second phase is the improvement phase, and aims to find a better feasible schedule. Costs are not always measured as money, but in case of a VRP, also as travel time, number of trucks or number of containers in time and so forth. In the vehicle routing problem with containers, this means that the heuristic allocates containers to trucks, such that the routes of the truck are feasible, and the costs are minimized. The remainder of this section describes the parameters and the settings in the improvement phase.

Parameters

The input solution from the construction phase is used as the current and the best solution found so far. The following parameters are necessary to start the improvement phase and will be explained:

- Start temperature T_{start}
- Stop temperature T_{stop}
- Current temperature T
- Cooling factor c
- Length of Markov Chain K

Simulated annealing works as follows. The length of the Markov Chain K determines the number of iterations with the same temperature. The temperature determines the probability of accepting a worse solution. After K iterations, the current temperature T decreases with a cooling factor c to $T \cdot c$. The heuristic starts at the start temperature of T_{start} and stops when the current temperature T is lower than the stop temperature T_{stop}. The output is the best solution found. Algorithm 1 shows the pseudo code for Simulated Annealing (adjusted from Pirlot, 1996).

Settings of parameters

To escape from local optima, the heuristic sometimes accepts worse neighbor solutions. The acceptance probability determines whether to accept or reject a worse neighbor solution. The probability is higher when the temperature is high. A low temperature means that less worse neighbor solutions are accepted. The formula for calculating this acceptance probability is as follows.

$$\text{acceptance probability} = e^{\left(\frac{\text{costs current solution} - \text{costs neighbor solution}}{\text{temperature}}\right)} \tag{3.8}$$

The acceptance ratio χ can be used to determine the start temperature T_{start}. This is the ratio of accepting worse solutions divided by the total number of proposed feasible solutions. The start temperature is set such that the acceptance ratio is high (almost 1) and the stop temperature is set such that the acceptance ratio is low (close to 0). Figure 3.3 shows the acceptance ratio relative to the temperature. We start with a high start temperature on the right of the figure and when the temperature cools down, the acceptance ratio is almost 0.

Algorithm 1 Simulated Annealing

Input: initial solution S_{init}, start temperature T_{start}, cooling factor c, Markov Length K

Initialization:
$T_{current} \leftarrow T_{start}$
$S_{current} \leftarrow S_{init}$
$S_{best} \leftarrow S_{init}$

while $T_{current} > T_{stop}$ **do**
  for $i = 1$ to K **do**
    $S_i \leftarrow$ neighbor($S_{current}$)
    if F(S_i) $\leq$ F($S_{current}$) **then**
      $S_{current} \leftarrow S_i$
      if F(S_i) $<$ F(S_{best}) **then**
        $S_{best} \leftarrow S_i$
      end if
    else if $\exp \frac{F(S_{current})-F(S_i)}{T_{current}} \geq rand()$ **then**
      $S_{current} \leftarrow S_i$
    end if
  end for
  $T_{current} \leftarrow T_{current} \cdot c$
end while

Output: S_{best}

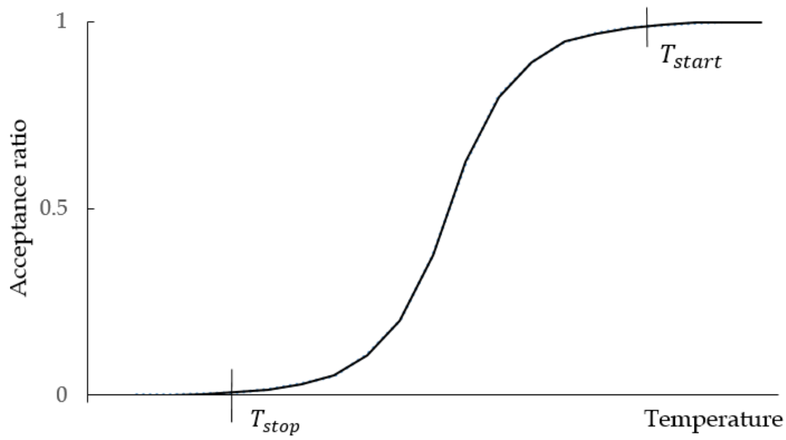


Figure 3.3: Acceptance ratio, adjusted from Schutten (2013).

Johnson (Johnson, Aragon, McGeoch, & Schevon, 1989) proposed to set T_{start} equal to $\frac{-\Delta C}{\ln \chi}$, in which ΔC denotes the average deterioration value. That is the sum of all objective values of solutions worse than the initial solution, divided by the total number of worse solutions. The performance of the initial solution is based on the value of the construction phase.

The number of neighbors at one temperature level K is the length of the Markov Chain K and is arbitrary, but should be enough to explore the complete neighborhood. K may be temperature dependent, which would mean that K_T is low when the temperature is high, to prevent that too many worse solutions are found. The cooling factor c determines the number of steps to finish the heuristic before it reaches T_{stop}. The heuristic takes more time if the cooling factor is close to 1. If there is a fixed amount of time available and we know the time needed for one iteration, we calculate the cooling factor as follows.

Assume that we want to let the heuristic run for 15 minutes and that one iteration takes 0.1 seconds. We take the length of the Markov Chain as 100. So, before the temperature decreases, this takes $0.1 \cdot 100 = 10$ seconds. We have time to run for 15 minutes, so that is $N = \frac{15*60}{10} = 90$ steps to cool down from T_{start} to T_{stop}. Let $T_{start} = 100$ and $T_{stop} = 0.1$, then we need c to be such that the following equations hold:

$$\begin{aligned} 100 * c^{90} &\leq 0.1 \\ c^{90} &\leq \frac{0.1}{100} = 0.001 \\ c &\leq \sqrt[90]{0.001} = 0.9261 \end{aligned}$$

So we have the cooling factor c such that

$$c \leq \sqrt[N]{\frac{T_{stop}}{T_{start}}} \qquad \text{with } N = \frac{\text{available time}}{\text{time per iteration} \cdot \text{length of Markov Chain}} \tag{3.9}$$

Instead of a stop temperature, Johnson et al. (1989) proposed a different stop criterion, namely to stop if no better solution is found for five consecutive temperature decreases. The combination of both is also possible.

Finding neighbors

Neighbor solutions are slightly changed compared to the related current solution, because the jobs are allocated in a slightly different way compared to the current schedule. This means in the truck scheduling case that two jobs are swapped between the containers, but the rest remains the same. We distinguish moves between routes (inter-route change) and within a route (intra-route change), where the allocation of jobs on trucks changes.

Inter-route mechanisms are swapping and moving of jobs between two different trucks. Figures 3.4 and 3.5 show this mechanisms. The number of jobs to change at a time is denoted with the length of the sequence of jobs.

(a): Before

(b): After

Figure 3.4: Move job j_3 after j_6.

(a): Before **(b):** After

Figure 3.5: Swapping jobs j_3 and j_6.

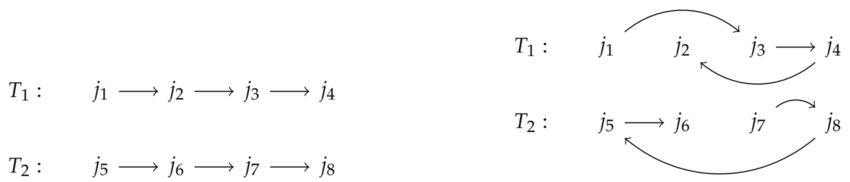
Crossing the routes may be interesting as well. By this we mean that the complete routes of the trucks are switched after a certain job. Figure 3.6 shows the crossing of two routes.

(a): Before **(b):** After

Figure 3.6: Crossing routes from job j_3 and j_6.

Or (1976) proposed in his paper Or-opt. Or-opt starts with a string of three jobs and inserting the string in another route. If this does not improve the costs function after some repetitions, the string reduces to two jobs, and after that, to only one job.

r-opt is an intra-route improvement operator. r trips are removed and replaced to construct 2^{r-1} new neighbors. The best neighbor is chosen. If $r = 2$, this can be compared with swapping one job, but then on different jobs.



(a): Before **(b):** After

Figure 3.7: Swap within a route

3.2.2 Conclusions on solution methods

This section answers the research question 'Which solution methods can be used to solve the container transport scheduling problem?'. We provided a list with solution methods for vehicle routing problems, which can be sued for container transport scheduling. The solution methods are exact methods and heuristics. We chose a heuristic because these are in general good in finding a good solution in an acceptable amount of time. The proposed solution method is simulated annealing.

3.3 Decision support

This section describes literature related to the research question 'What is known about implementing decision support?'. Decision support is used for the planners, to get insight in the network. Before implementing a DSS, we need to know what aspects have to be taken into account.

Goetschalckx and Taylor (1987) describe three benefits and three requirements for a Decision Support System (DSS). The benefits are the reduced dependence on personnel experience, enhanced job environment and faster response time, and improved decision quality. However these benefits make it obvious for every company to use a DSS, this is not seen in real life situations. If the system does not fulfill the requirements, the system will not be accepted and used. The 'minimal' requirements for a DSS to be used and to be successful are that, it must be realistic and efficient, inexpensive to acquire and to modify, and easy to use and enhance the job. Besides this, there are additional subjective requirements as the introduction of the system and training facilities.

It is difficult to design a system for synchromodal transportation which fits for all users (P. M. Singh, 2014). The benefits of an IT-platform for synchromodal transportation are numerous and have positive effects on the business, society, and general well-being. But before such a system can be implemented, Singh mentions that it is important that stakeholders get insight in the system, for example by a game visualizing the way of solving the problem. The research is still in progress, so there are no results available yet.

3.3.1 Conclusions on decision support

To have a successful implementation of a DSS it must fulfill three requirements, it should be realistic and efficient, inexpensive to acquire and to modify, and easy to use and enhance the job. Besides this, the involvement of stakeholders in each step in the implementation process is very important.

3.4 Conclusions on literature review

This chapter described the literature related to the research question 'What is known in academic literature about container transport scheduling?' The section described the following aspects:

- Section 3.1 addressed the question which type of problem from literature is related to the core problem. We proposed the vehicle routing problem, because this involves the allocation of demand (containers) on resources (trucks) and the routing of the trucks. The characteristics of the VRP instance at CTT are:
  - Vehicles with fixed capacities
  - Heterogeneous fleet
  - Time windows at customers, terminals and for resources

  - Pick up and delivery
  - Release and due dates
  - Multiple depots
  - Full truck load
- In Section 3.2, we looked at solution methods for the vehicle routing problem. Heuristics are appropriate for this type of problems, because they are able to find good solutions in an acceptable amount of time. The simulated annealing heuristic is chosen as a method to support the scheduling of trucks and containers. Furthermore, the section described the parameters for simulated annealing and the setting of the parameters.
- Section 3.3 addressed the implementation of a decision support system. Before implementing a decision support system, we have to be sure that the system will be accepted by the people that work with the system. Otherwise, the situation may not improve.

Chapter 4

Solution design

This chapter describes the solution method for the problem by answering the third research question 'How can container transport scheduling for trucks be supported?'. We aim to provide the truck planners with decision support. Chapter 3 provided background information for this model. Knowledge of the employees at CTT, own insights, and the literature is used to construct solutions methods are for the features of a decision support tool.

This chapter starts with use cases in Section 4.1, to show some situations where the model should ideally be able to cope with. These are historic events at CTT. Section 4.2 describes the theoretical model. Section 4.3 presents the solution methods for the different functionalities, based on the theoretical model. We reflect on the sub questions in the conclusions of this chapter in Section 4.4.

4.1 Use cases

This section presents use cases at CTT to show some situations at CTT where decisions support might have helped. At the moment of occurrence of the situation, a lack of visibility in the network and missing decision support led to non-optimal decisions. The use cases show that it is hard for planners to oversee the whole situation. In some of the use cases, the synchronization of information could improve the results.

In the upcoming figures, green circles represent customers and blue rectangles terminals of CTT. The text next to arcs represents the steps in the route, the modality, and the containers to transport. For example, 3: T_1^b means that in the third step, truck 1 transports container b. TR indicates the modality train, T_i truck i, and B a barge. To follow the route, the steps, the first number, must be followed. If there are multiple arcs with the same number, this indicates that these steps can be performed simultaneously.

Use case 1: Merging trips
Assume that there are two jobs, one pickup job and one delivery job. These jobs are performed after each other, because there is no information available of the job at customer C_2 when the

truck departs without container at customer C_1. If this information would be available, these two jobs can be merged to one, as can be seen in Figure 4.1. The saved distance and time has to be taken into account, but also the deadline of other jobs.

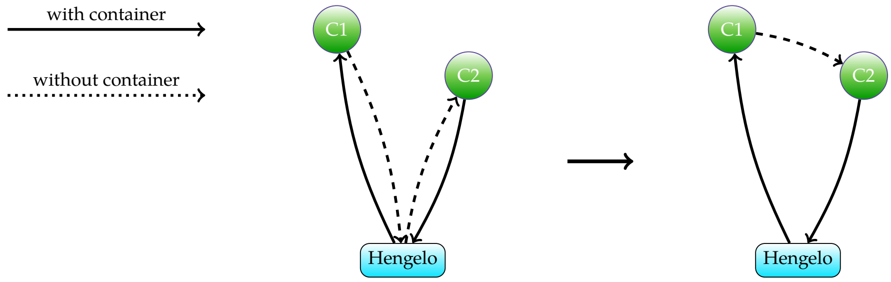


Figure 4.1: Example merging of two single trips.

Use case 2a: Train not full

Suppose the train from Rotterdam to Bad Bentheim has ten places left and there are still containers to transport to Enschede. When the containers are placed on this train, this means that ten containers should be transported from Bad Bentheim to the customer, which is in Enschede. Besides the increased distance between Bad Bentheim and Enschede compared to Hengelo and Enschede, there are not enough trucks in Bad Bentheim. This means that trucks should drive empty to Bad Bentheim. We have to weigh the 'costs' of empty spaces on the train and costs for the additional trucking. Insight in the network by means of decision support helps to take this decision.

Use case 2b: Hub in Coevorden

Another example is the situation that CTT can use the train in Coevorden for ten containers, see Figure 4.2 and 4.3. If these are 20ft containers, ten trucks are needed to transport the containers from Hengelo to Coevorden and drive back without container, because it is not possible to unload the container at the front of the chassis otherwise. This can be solved by using five trucks with each two 20ft containers and a special truck. The chassis are decoupled at a hub nearby the terminal in Coevorden. One of the trucks stays and transports the containers between this hub and the terminal to be transshipped to the train by a reach-stacker for example. The other four trucks continue.

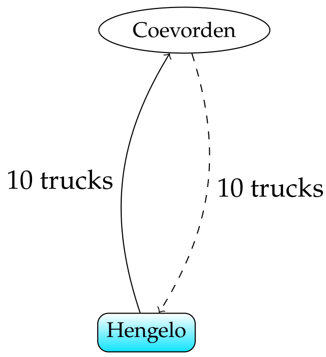


Figure 4.2: Ten trucks are needed to transport containers to the terminal in Coevorden.

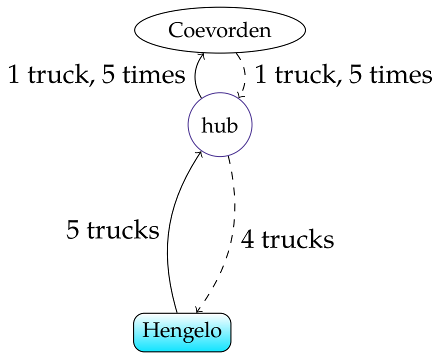


Figure 4.3: Five trucks are needed to transport containers to the terminal in Coevorden.

Use case 3: From two trucks to one truck

Suppose that there are two containers, a and b, that need to be transported to the customers to be loaded or discharged and need to go back to the terminal. Container a is nearby the terminal in Hengelo and container b nearby Bad Bentheim. One truck drives from Hengelo to customer C_1 to load container a and drives back to Hengelo. The second truck departs from Bad Bentheim, to customer C_2 to load container b and drives back to bad Bentheim. Both containers are now in time to depart on time to Rotterdam by barge and train. This can be seen in Figure 4.4.

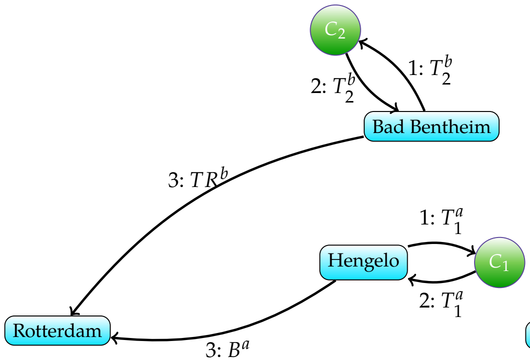


Figure 4.4: With two trucks.

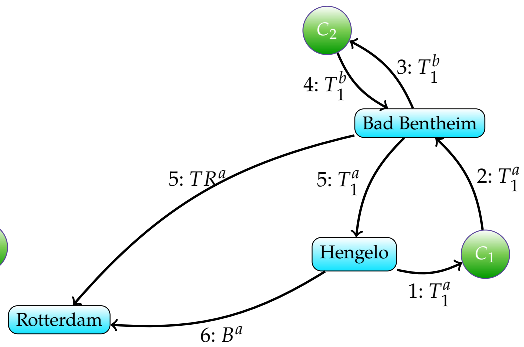


Figure 4.5: With one truck.

In Figure 4.5 the same situation is sketched, but now there is only one truck needed. This can be done by by decoupling container a in Bad Bentheim and continue with the job for container b. This results in less vehicle costs, but additional handling costs in Bad Bentheim. These two costs should be offset, to take the best decision.

Use case 4: Continuously updating information

Suppose there are three jobs in the network, one truck is available, and space is left on the barge and train. The jobs and the situation are sketched in Figure 4.6. Customer C_2 is located

- J_1: Deliver container a from terminal Hengelo to customer C_1.
- J_2: Deliver container b from stock in Bad Bentheim for customer C_2 to Rotterdam.
- J_3: Deliver container c from stock in Hengelo for customer C_3 to Rotterdam.

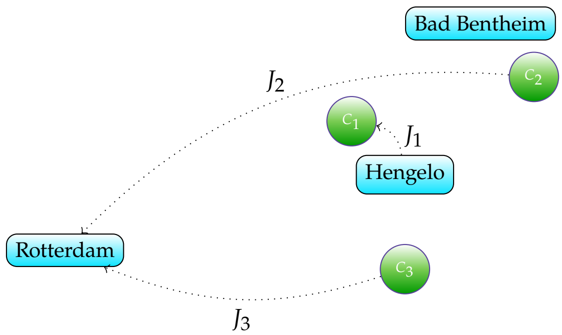


Figure 4.6: Jobs in the network.

nearby Bad Bentheim and C_1 and C_3 are close to Hengelo. First the container a for customer C_1 is delivered. It makes sense that the container b from C_2 is transported by train from Bad Bentheim and c from C_3 by barge from Hengelo. Taking into account the time windows at the customers, the route of the truck becomes as in Figure 4.7.

This route can be further optimized when container b of customer C_2 is transported directly to Hengelo. The route of the truck can be seen in Figure 4.8.

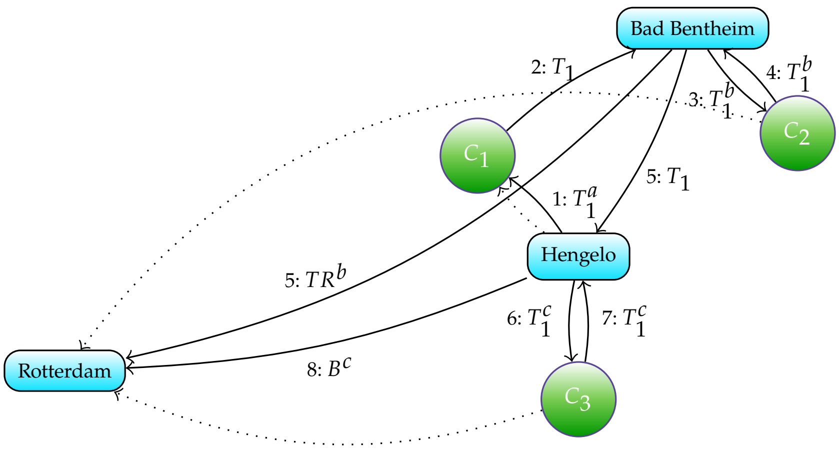


Figure 4.7: Route in the network.

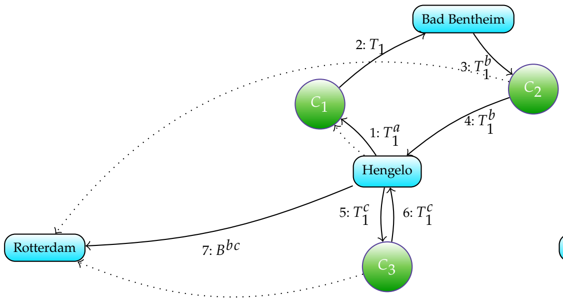


Figure 4.8: Updated route in the network.

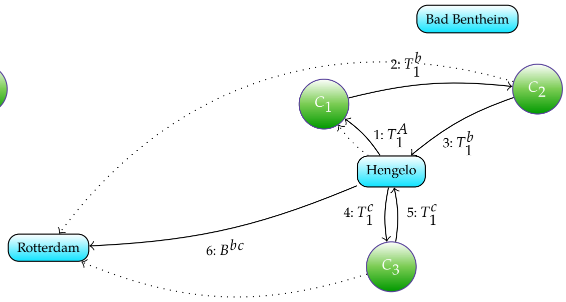


Figure 4.9: Best route in the network.

In this way, the distance of the truck decreases, the amount of empty miles decreases and the container of C_3 is at the terminal in Hengelo on time. This can be further optimized if there is an empty container at C_1 available which can be used by C_2. This can also be seen in Figure 4.9.

All examples support the need and opportunities for decision support. These are instances that can be recognized by software packages, but this is hard for truck planners.

4.2 Conceptual model

This section describes the conceptual model with its assumptions, based on the case of CTT. The section addresses the sub question 'How can the conceptual model be described?'.

The solution method aims to find a feasible route for each truck. A route is feasible if the total driving hours of a truck do not exceed 9 hours per day and total working hours do not exceed 13 hours per day. If the truck drivers drives for more than 4.5 hours, he first takes a break of 45 minutes and then executes the job. Furthermore, a container is allowed to arrive between the start and the end of the hard time window at the customer. This means that a container waits if it arrives before the start, and the schedule is not feasible if the containers arrives later than the end of the hard time window. However, it is allowed that the container departs later than the end of the hard time window, but the service should start before the end of the hard time window.

A truck transports one container at a time, and the length of the container must be the same as the chassis length, which is 20, 40 or 45 TEU. Jobs for a sideloader need to be transported by a sideloader, for which the length of the container does not matter, because the length of a sideloader is adjustable. A sideloader is able to move a container on and off its own chassis. Also tilting chassis are incorporated in the model, for which the size is not relevant as well. Jobs should be performed exactly once by exactly one truck. The trucks start at one of the terminals and end at the closest terminal of the last job. We assume that all truck drivers can transport all types of containers, for example, dangerous goods, and that they all drive at the same speed. The average speed depends on the distance between two locations. The distances are calculated with Google Maps.

For the locations we assume that they are opened the whole day and that there is personnel present to load or discharge the container when this should be done immediately.

Furthermore, we assume that all containers are available at the beginning of the day, except the jobs in which a pick up job follows a delivery job on the same day. This means that a container should be finished with loading or discharging, before it is returned to an inland terminal.

The result of the solution method is a feasible schedule with routes and jobs for the trucks, and thus also the number of trucks that are needed. The schedules provides information about which containers the truck should transport and in which sequence. A mathematical formulation of this problem can be found in Appendix F.

4.3 Solution methods

This section addresses the sub question 'Which methods can be used to provide the functionalities?'. The section describes the solution methods for the functionalities described in Section 2.5. Each of the following sub sections describes one functionality.

The relation between the latest departure time, number of trucks, and the offline schedule is shown in Figure 4.10.

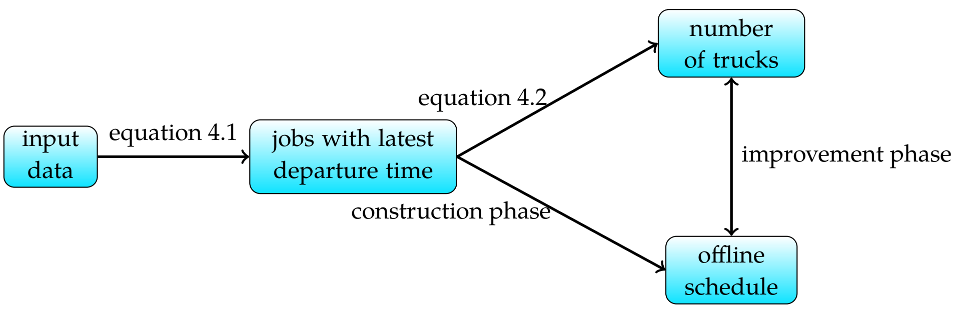


Figure 4.10: Process

The input data is retrieved from Modality, but needs several steps. Modality, Microsoft Excel, phpMyAdmin, and Google Maps are used to transform the data to input data for the model, which is programmed in Plant Simulation. Appendix G describes the details of the data gathering process. The latest departure time and the number of trucks are used as input for the offline schedule. The construction phase of simulated annealing provides an initial schedule. The improvement phase of simulated annealing results in a loop between the number of trucks and the offline schedule. This is also the output of the model as programmed in Plant Simulation. The following sub sections describe the methodologies in more detail.

4.3.1 Scheduling on departure time

One of the missing functionalities of the current system is that it is only registered at what time the container should be at the customer or at a terminal. The distance and travel times are not available in the system for every container. This means that the latest departure times for containers are not available in the system. Experienced truck planners are able to estimate the travel time for containers and can always look up the travel time at Google Maps for example, but this takes a lot of time when this should be done for around 300 containers per day. If the latest arrival time and the travel time are known, the latest departure time can be calculated. Since the travel time is not always known, we use the next formula:

$$\text{latest departure time } = \text{latest arrival time } - \frac{\text{distance}}{\text{average speed}} - \text{decoupling time} \tag{4.1}$$

The average speed depends on the total distance and incorporates delays as traffic jams and traffic lights. On short distances, the average speed is lower than on longer distances, where the trucks drive mainly on highways. The decoupling time is the time to decouple a container if this is necessary.

When the latest departure time is known for each container, truck planners can sort their containers on latest departure times of containers and assign containers to trucks in this way. This is more clear compared to the method used nowadays, in which the containers are sorted on latest arrival time at the customer. This feature already support to prioritize the containers.

4.3.2 Number of trucks needed

A lower bound for the number of trucks needed for a day is interesting, because it shows if there are additional trucks needed for a day. Ideally, all jobs are divided over all trucks and all truck drivers work and drive for the maximum amount of time. Therefore, it is possible to give a lower bound for the number of trucks, because it may happen that not all jobs fit exactly in the time restrictions of the trucks. In that case, there are more trucks needed. Equation 4.2 gives a lower bound for the number of trucks needed to fulfill the jobs. The following aspects are necessary:

- For the jobs:
  - Travel time of job (TT_j)
  - Travel time to travel to start of job from nearest inland terminal(TT_j^{start})

  - Travel time to travel from end location of job to nearest inland terminal (TT_j^{end})
  - Service time of job (ST_j)
- For the trucks:
  - Maximum allowed driving time per truck ($MaxDrive$)
  - Maximum allowed working time per truck ($MaxWork$)

Then the minimal number of trucks is:

$$\text{min. number of trucks} = \max\left\{\left\lceil\frac{\sum_j TT_j + TT_j^{start} + TT_j^{end}}{MaxDrive}\right\rceil, \left\lceil\frac{\sum_j TT_j + TT_j^{start} + TT_j^{end} + ST_j}{MaxWork}\right\rceil\right\} \tag{4.2}$$

The travel times between jobs are detours and are not fixed. The lower bound for the number of trucks is more reliable when it is possbile to make an estimation of the detours. TT_j^{start} and TT_j^{end} represent the travel times from the jobs to the nearest terminal. If the job start or finishes at an inland terminal, the value is equal to zero. The lower bound for the number of trucks is used as input for the offline scheduling, but is also updated in the improvement phase. Figure 4.10 shows this process.

4.3.3 Offline scheduling

The offline schedule is the initial schedule for one day, made before any jobs are performed. The offline schedule does not take into account the changes in resources and demand during the day. The schedule provides feasible routes for trucks such that, for example, the total time that containers are too late is minimized. Section 3.2 discussed the different solution methods for vehicle routing problems described in literature. We use simulated annealing as a heuristic to find an initial truck planning for one day at CTT. In this section, we describe the settings of our simulated annealing heuristic for scheduling trucks in more detail.

In short, the model gives an initial feasible solution and then further improves the solution. A solution is feasible if:

- For the jobs where decoupling is allowed, the sequence of delivery and pick up of the container must be correct. Furthermore, the service on the container must be completed, which is the loading or discharging of the container.
- The working and driving hours of trucks drivers do not exceed 13 and 9 hours respectively, due to driving hours restrictions (European Parliament, 2015). The working hours are reduces with a break of 45 minutes, but do not influence the working hours.
- The containers are delivered within the hard time window.
- The trucks ends the working day at an inland terminal.

Figure 4.11 describes the construction of an initial feasible solution. First, the heuristic sorts the jobs and then allocates the job to the truck with which the container arrives as first. Figure 4.12 shows the improvement phase, where the initial solution is improved. A neighbor solution also

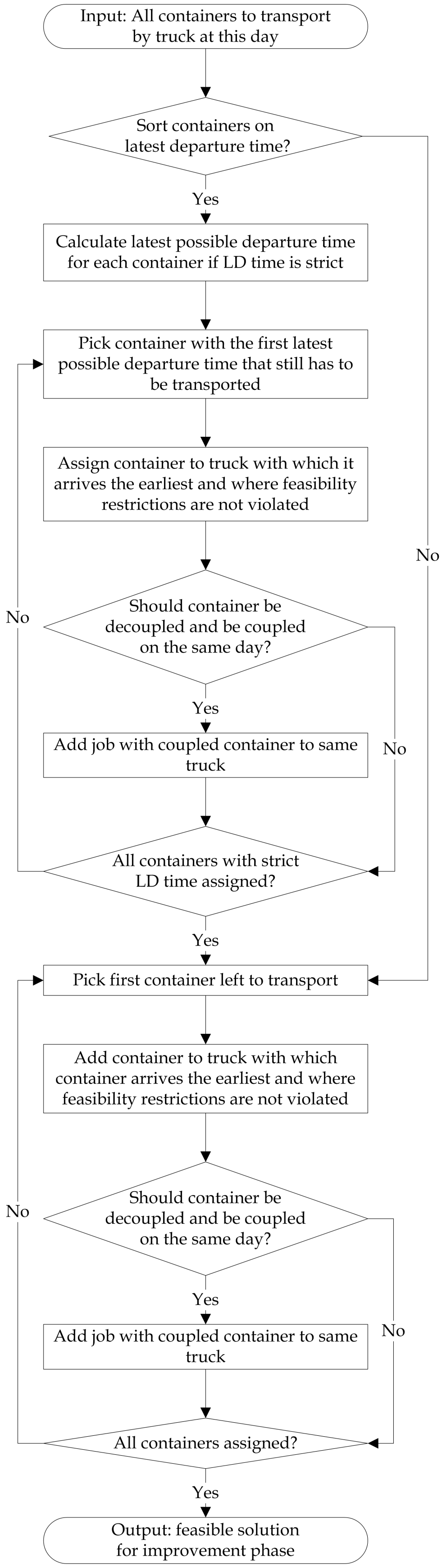


Figure 4.11: Flowchart heuristic - construction phase

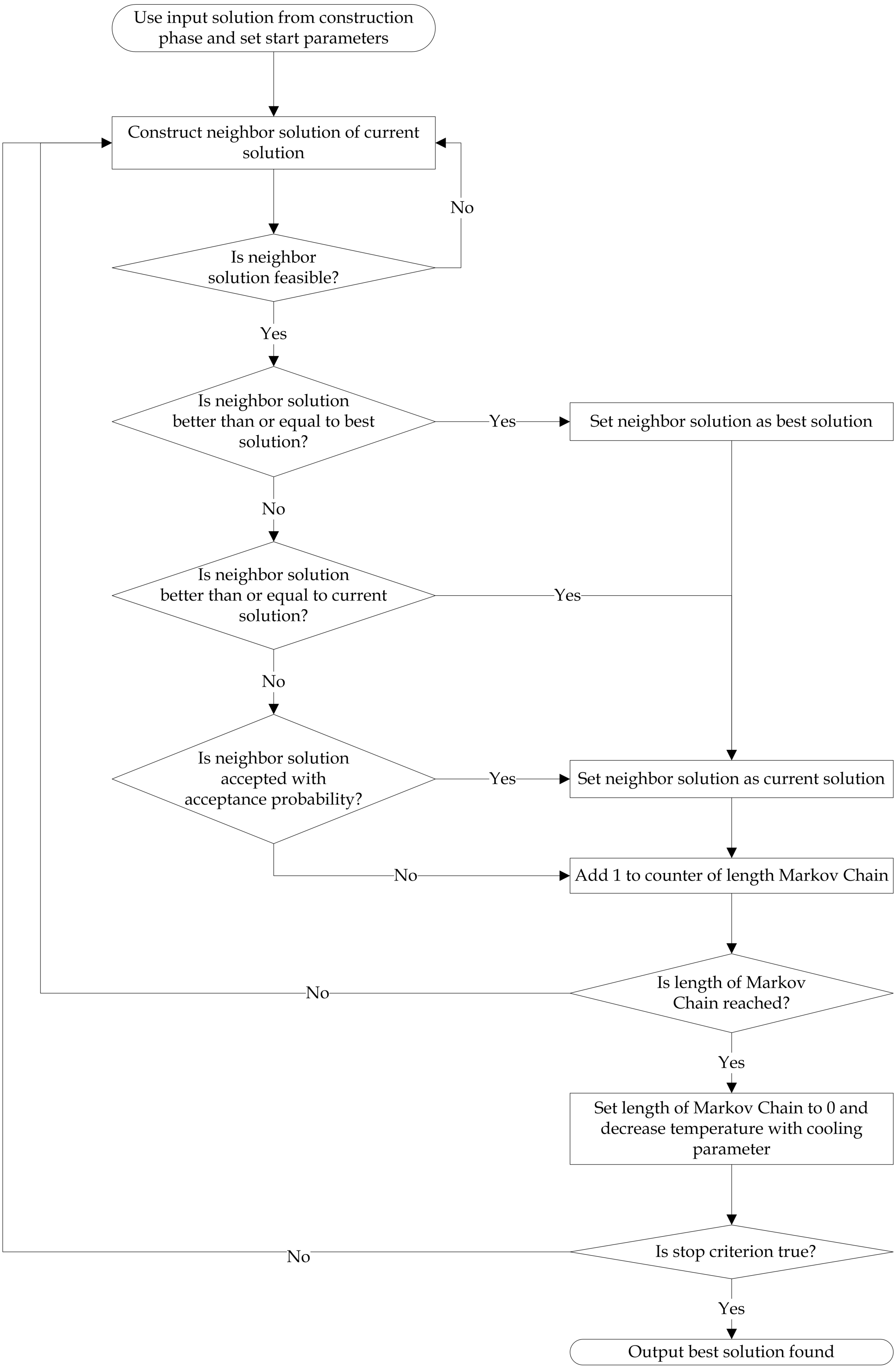


Figure 4.12: Flowchart heuristic - improvement phase

a set of routes for trucks, but slightly differs from the current solution. Improvement operators are used to construct a neighbor solution and these are listed below.

- Inter-routes operators
  - Move job(s) from one truck to another truck
  - Swap job(s) between two trucks
  - Cross routes of two trucks
- Intra-route operator
  - Swap jobs in route of one truck

Each operator has its own feature. The number of trucks will always be the same when using the swap operator. The cross operator is able to move two sequences of jobs between two trucks. This may cause infeasibility of the length if one of the sequences is much longer compared to the other, because this may result in a very long route for one truck and a very short route for the other truck. The move operator is able to remove jobs from a truck, which means that the move operator is able to reduce or increase the number of trucks needed. The different features of the operators are all interesting, so the heuristic should be able to deal with all operators and also a combination.

This solution method is programmed in Plant Simulation. The flowcharts in Figure 4.11 and 4.12 describe the methods that are used, but the specific settings for the parameters are discussed in Section 5.1. Appendix H describes the methods in the Plant Simulation model.

The following two functionalities, online scheduling and synchromodal scheduling, are not implemented in Plant Simulation, but a description of how this can be added is given.

4.3.4 Online scheduling

The online schedule takes into account the current status of the resources and demand, for example if the job is done already. The online schedule gives a suggestion about the container to transport next. This sub section describes in short an approach to do this.

The following information is needed:

- List with all jobs (demand)
  - Locations to visit for each job
  - LD time for job, if relevant
  - Availability of job (after decoupling for example)
  - Status of job (performed or not)
- List with all trucks (resources)
  - Location of truck
  - Chassis of truck
  - Availability of truck
- Available chassis

The offline scheduling approach can be adjusted manually with data of jobs that are already finished and the ‘start’ time of trucks. The start time of a truck is in this case the time at which the truck is available for a new job. In the same way, the start location of the truck should be changed. For the jobs we can set 'To do' feature to 'TRUE' if that job is finished. When this information is changed manually, the program is able to calculate a new schedule.

4.3.5 Synchromodal scheduling

As a start for synchromodal scheduling, the flexible option to deliver export containers at one of the inland terminals instead of at a predestined inland terminal can be added. This is relevant for containers that continue by barge or by train. In the same way, we can change the arriving inland terminal. This means that the jobs are changed, because the 'to' location changes from CTT Hengelo to CTT Bad Bentheim for example. In the future, this can also be extended to changing the sea terminal.

4.4 Conclusion

This chapter described the solution method. The research question for this chapter is: 'How can container transport scheduling for trucks be supported?'. The answers to the sub questions are as follows:

- Section 4.1 described situations at CTT which can be avoided with the use of decision support, because there is an information overload. As an example, the merging of trips is shown. Other examples involve a different inland terminal for a container, which means that another long haul mode is used (for example train instead of barge), because this results in less truck costs.
- Section 4.2 described the theoretical model of the problem. This involves assumptions as one container per truck and the average speed, but also the key performance indicators for a schedule.
- Section 4.3 addressed the solution methods for each of the support functionalities. The latest departure helps to sort containers for the truck planners and is calculated by subtracting the travel and decoupling time from the latest arrival time of a job.

  A minimum number of trucks can be given based on the total travel time and total travel and service time, divided by the available time per truck. It must be noted that this minimum is rarely the actual number of trucks, because it does not take detours into account.

  The offline schedule gives a guidance for a day. This schedule can be used to find bottlenecks and anticipate on this. The schedule is built by creating a random initial feasible solution and then improved by swapping and moving jobs, according to the simulated annealing heuristic.

  An online schedule incorporates changes in resources and demand during the day. The newest information, that is the availability of containers and trucks, is used to update the schedule and can be used to decide which container should be transported next. The section described a stepwise approach to adjust the method of finding an offline schedule, to use the current solution method also to create the online schedule.

The first step to synchromodal scheduling is the flexible choice in barge, train, and truck. This can be modelled by changing the location of the inland terminal if this is in Bad Bentheim or in Hengelo. This is most interesting for jobs located in the area between Hengelo, Bad Bentheim, and Almelo.

Chapter 5

Solution tests

This chapter addresses the research question 'What are the best settings to improve the performance with using decision support for container transport scheduling?'

Section 5.1 describes the different scenarios and experimental factors of the simulated annealing algorithm. Section 5.2 describes the experiments that result from these parameters. Not all combinations of parameters and scenarios are tested, because this takes too much time. Section 5.3 presents the acceptance ratios and costs curve of some of the experiments, to verify the model. Section 5.4 presents the results of the experiments and describes the main findings based on these results. Section 5.5 describes the results of the experiments in which for example the length of the time window varies. Section 5.6 ends this chapter and summarizes the answers on the research questions.

5.1 Experimental set-up

This section describes the experiments and the parameters of the experiments. First, Section 5.1.1 describes the assumptions for the solution method. Second, we describe all parameters that can be set in Section 5.1.2. Section 5.1.3 describes different situations for which scheduling may need a different approach.

5.1.1 Assumptions for model

This section describes the assumptions for the solution method. These are estimated based on experiences of truck planners and own insights. First, we assume that the average speed is dependent on the total distance. On short distances, the speed limits are generally lower and there are also more traffic lights. Longer distances incorporate driving at highways as well, where the speed limit is higher. Nevertheless, it take some time to reach the highway, and there is also chance on traffic jams. Table 5.1 shows the average speeds for different distances that are used in the solution method.

Table 5.1: Average speed for distances

Distance	Average speed
Less than 3 km	40 km/h
Between 3 and 20 km	55 km/h
More than 20 km	70 km/h

Second, the model assumes that decoupling/coupling takes 15 minutes per job and loading/discharging takes 45 minutes per job. There is no time incorporated in the model for the handling of containers at the terminal.

5.1.2 Experimental factors

The experimental factors are split up in the categories: optimization goal, initial solution, improvement operators, number of jobs per operator, stop criterion, and other experimental factors. These factors are related to the simulated annealing algorithm.

- **Optimization goal.** The optimization goal determines the goal of the simulated annealing algorithm. For example, if this is to minimize the total number of trucks, the costs are the number of trucks and we want to minimize this value. The value of the costs related to this goal are used to compare with the current and best solution so far. All goals need to be minimized.
  - Number of containers delivered after LD time (not in time)
  - Total lateness of containers that are delivered after LD time (time too late)
  - Number of containers delivered outside soft time window (not in TW)
  - Total lateness or earliness of containers that are delivered outside soft time window (time not in TW)
  - Number of trucks
  - Travel time
  - Waiting time
  - Number of detours
  - Total time of detours (detour time)
- **Initial solution.** The initial solution for the improvement phase of simulated annealing can be provided in two ways. With a random initial solution, there is more room for improvement. Sorting on latest departure time may be interesting when the number of containers too late, or the total time too late, should be minimized.
  - Random feasible initial solution
  - Sorted on latest departure time
- **Improvement operators.** To improve the initial solution, different operators are used to find neighbor solutions.
  - No improvement operator (only initial solution)
  - Inter-route improvement operators
    - Swapping jobs
    - Moving jobs
    - Crossing routes

    * Combination of above, with probabilities:
        · P(swap)=0.34, P(move)=0.33, P(cross)=0.33
  - Intra-route operators
    * Swapping jobs
- **Number of jobs for improvement operator.** It is possible to move or swap a sequence of jobs instead of only one job. This works as follows.The heuristics starts with moving and swapping a sequence of three jobs. For the crossing of routes this means that there are at least three jobs moved. After one third of the iterations, the length is decreased to 2, and after two-third, decreased to 1 job. Intra-route swapping only swaps a sequence of one truck with the same length of the sequence on a different truck. The sequence of jobs can have different lengths.
  - Always one job
  - First three, then two jobs, later one job (Or-opt).
- **Stop criterion.** The stop criterion determines when the heuristics finishes, and thus when to output the best solution found.
  - When both hold
  - Stop temperature
  - No improvement for N consecutive temperature decreases
  - When one of the above holds
- **Other experimental factors.** The specific parameters for the SA algorithm are important to check if all possible neighbors can be found and too see if the acceptance ratio fulfill the requirements. These factors are used to verify the model.
  - Start temperature
  - Stop temperature
  - Cooling factor
  - Length of Markov Chain

5.1.3 Scheduling scenarios

A scheduling scenario is related to the input for the model, which is the set of containers to transport with, amongst others, different travel times and time windows.

We use the data set of 23^{th} of July 2015 as the initial case study. In the enumeration below, 'current situation' indicates this original data set. On this day, 279 different containers are transported. We remove one container from this data set for our model, because it cannot fulfill the requirements for the working hours for truck drivers, since it already takes more than 9 hours to drive to the customer.

Table 5.2 presents the type of trips at 23^{th} of July in this data set.

We see in Table 5.2 that there are in total 278 containers. 48 containers are decoupled and delivered and picked up at the same day. This means that we have 278 + 48 = 326 jobs in total.

Table 5.3 shows the gate OUT and gate IN moves per CTT's inland terminal. The table does not distinguish between the type of trips as mentioned in Table 5.2.

Table 5.2: Trips at 23^{th} of July

	Number of containers
Only Gate OUT	81
Only Gate IN	71
Decoupling	48
No decoupling	78
Total	278

Table 5.3: Moves per inland terminal

	CTT Hengelo	CTT Bad Bentheim	CTT Rotterdam	Total
Gate OUT	194	14	47	255
Gate IN	180	16	49	245
Total	374	30	96	500

Table 5.3 shows that most of the moves, 75%, are from and to the inland terminal in Hengelo. This can also be seen in Figure 5.1, where a larger icon represents more visits at that location. Furthermore, we see that in total 194 times a truck with a container departs from the inland terminal in Hengelo and 180 times arrives at the terminal. Figure 5.2 shows the region around CTT Hengelo and CTT Bad Bentheim. A blue icon represents a LD address and a green icon an inland terminal of CTT.

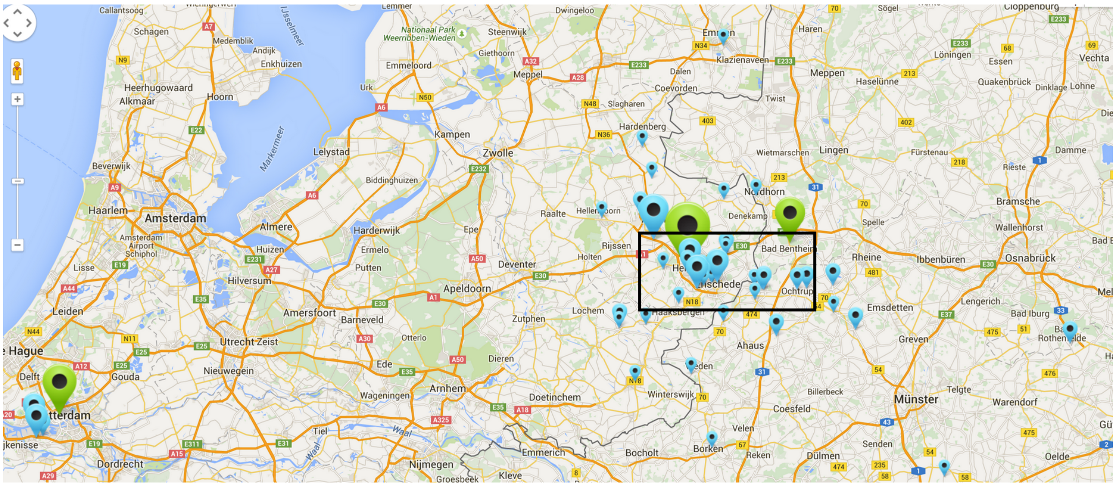


Figure 5.1: All addresses to visit on 23th of July.

Figure 5.3 shows the moves around CTT Hengelo and Bad Bentheim. A red arc represents a 'both' move, and a black arcs a single move (gate IN or gate OUT). The number on the arcs denotes the number of moves on this trip.

We see in Figure 5.3 that there are many red arcs, which are already from location A to B to A. This means that it is not possible to split or merge these jobs. The interesting jobs are indicated with the black arcs, for which merging is possible and therefore opportunities to improve the scheduling for these jobs.

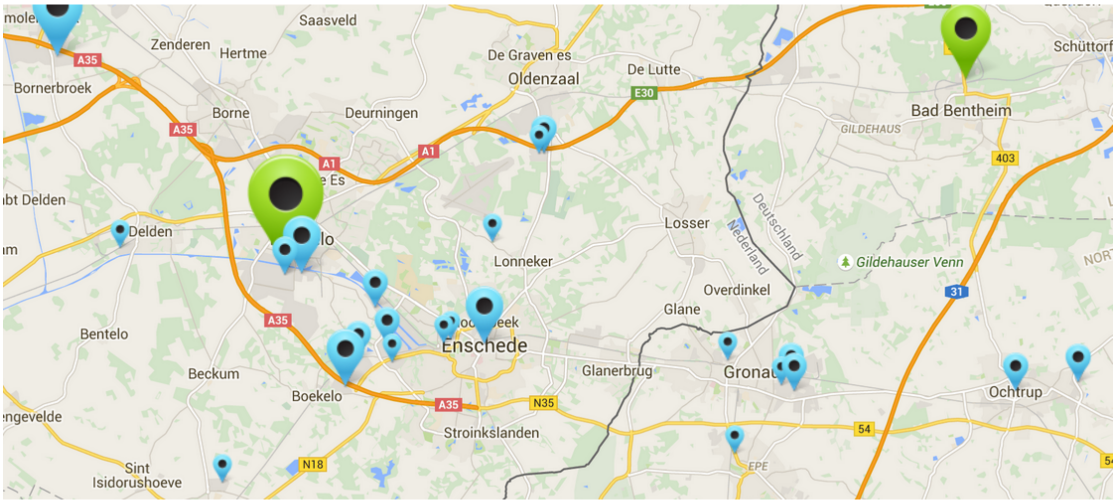


Figure 5.2: All addresses to visit on 23th of July, zoomed in on CTT Hengelo and CTT Bad Bentheim.

The different scheduling scenarios are related to decoupling, loading/discharge times, and time windows of containers. It must be noted that these scenarios are not validated at CTT, but are hypothetical scenarios. The enumeration below shows the possible scenarios.

- **Decoupling**
  - Current situation
  - Always decouple container
  - Never decouple container
- **Loading/discharge times**
  - Current situation
  - No loading/discharge times
- **Time windows**
  - Hard time window same as soft time window, with:
    - Soft time window of 5 minutes before and after LD time
    - Soft time window of 20 minutes before and after LD time
    - Soft time window of 1 hour before and after LD time
  - Hard time window three times larger than soft time window, with:
    - Soft time window of 5 minutes before and after LD time
    - Soft time window of 20 minutes before and after LD time
    - Soft time window of 1 hour before and after LD time

5.2 Experiments

We set up several experiments in which the settings of experimental factors and scenario differ. Table I.2 shows the settings for the experiments. We use experiment 4 as starting point for the experiments, because the timeliness is most important and therefore to have as less possible containers outside the time window.

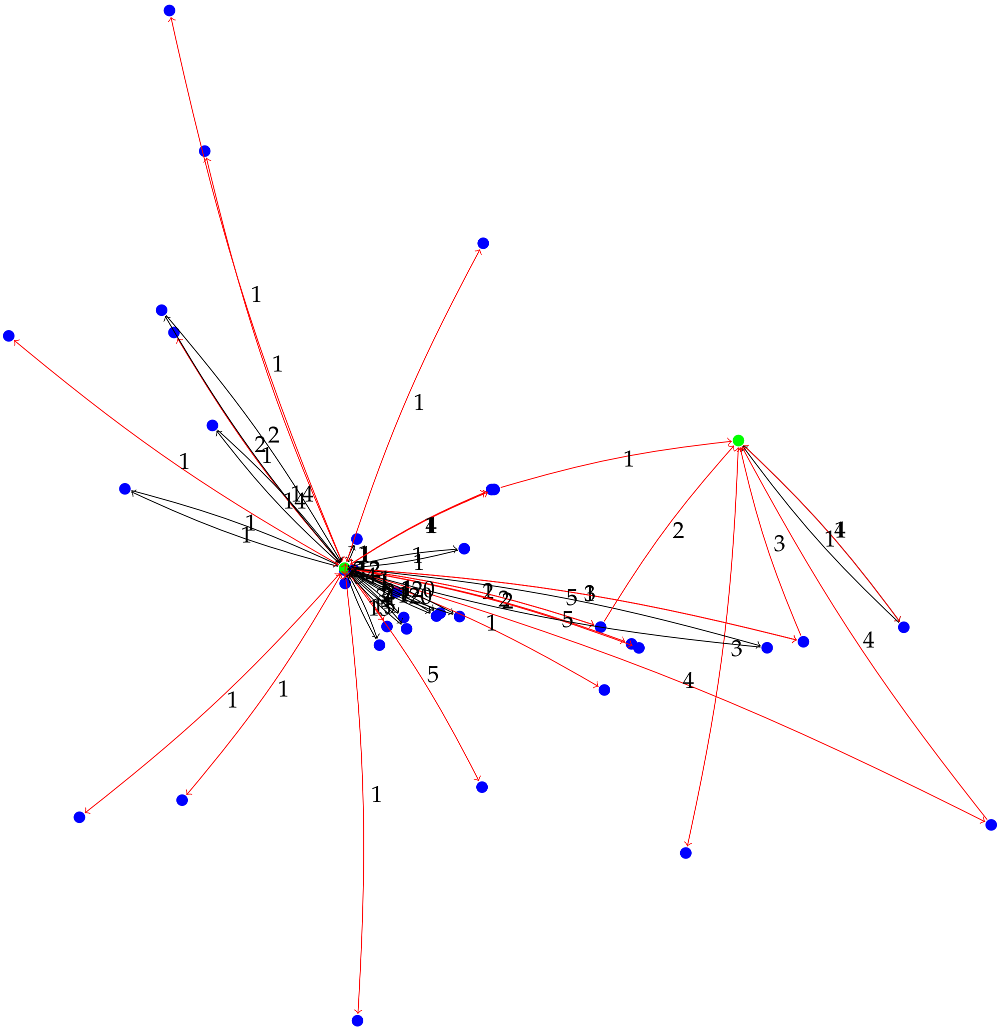


Figure 5.3: The jobs nearby CTT Hengelo and Bad Bentheim on 23th of July

The benchmark experiments (B1 and B2) only consider the construction phase, where the containers are sorted on respectively random and on latest departure time as described in Figure 4.11.

The results will be compared to the benchmark scenarios (Exp. B1 and B2) and the standard scenario (Exp 4.). First, we start with experiments with different optimization goals.

Optimization goal
The optimization goal determines which key performance indicator is used for the costs of a schedule.

Table 5.4: Experiments for optimization goal

Exp.	Optimization goal	Cooling factor	Start temperature	Stop temperature
1	Not in time	0.975	100	0.1
2	Time too late	0.975	50000	10
3	Not in soft time window	0.975	100	0.01
4	Time outside soft time window	0.975	50000	10
5	Total trucks	0.99	10	0.1
6	Total travel time	0.975	100000	5000
7	Total waiting	0.975	100000	10
8	Total detours	0.95	1000	1
9	Total time detours	0.975	50000	100

Improvement operators

The improvement phase of simulated annealing uses neighbor operators to cosntruct neighbor solutions. We experiment with the probability of choosing an operator and with the number of jobs that is swapped or moved with that operator. In case of crossing routes, we cross the routes starting at the first job that is chosen from a truck.

Table 5.5: Experiments for improvement operators

Exp.	Probabilities	Number of jobs for operator
4	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	3,2,1
10	P(cross)=1, P(move)=0, P(swap)=0, P(cross)=1	3,2,1
11	P(cross)=0, P(move)=1, P(swap)=0	3,2,1
12	P(cross)=0, P(move)=0, P(swap)=1	3,2,1
13	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	1

Time windows

In this group we test some hypothetical scenarios where the customer related parameters are different. These are restrictions for the time windows, which are dependent on the LD time, and also if the container should be decoupled or not.

Table 5.6: Experiments for time windows

Exp.	Soft time window	Hard time windows	Decoupling
4	20 minutes before and after LD time	1 hour before and after LD time	Customer dependent
14	20 minutes before and after LD time	20 minutes before and after LD time	Customer dependent
15	5 minutes before and after LD time	15 minutes before and after LD time	Customer dependent
16	5 minutes before and after LD time	5 minutes before and after LD time	Customer dependent
17	1 hour before and after LD time	3 hour before and after LD time	Customer dependent
18	1 hour before and after LD time	1 hour before and after LD time	Customer dependent

Stop criterion

The simulated annealing algorithm stops and outputs the best solution found when the stop criterion is true. The experiments test the different combination of a stop temperature and number of temperature levels without improvement.

Table 5.7: Experiments for stop criterion

Exp.	Stop criterion
4	Stop temperature and number of improvements
19	Stop temperature
20	Number of improvements
21	Stop temperature or number of improvements

Appendix I presents all experiments with all parameters in one table.

5.3 Validation and verification

The parameters of the model are based on expected averages from truck planners and own assumptions. Examples are the time needed for decoupling and the average speed of trucks to determines the travel time. Other assumptions, such as only one container per truck and only three types of containers, make it difficult to compare the model with the real situation. It is therefore not possible to validate the model based on real data. We discuss in Section 6.2 the consequences and recommendations regarding the validation.

Nevertheless, we are able to verify our own model. Several feasibility and verification checks are build in the Plant Simulation model while constructing the solution method. Examples are checks to verify that swapping jobs back from an infeasible solution, yield the old feasible solution. The methods also check if all jobs are still performed by exactly one truck. The settings of the start and stop temperature and cooling factor are checked using the acceptance ratio curve. Figure 5.4 shows the acceptance ratio for the 'Time not in time' KPI. Note that the model start with a high temperature (at the right hand side), and then decreases (to the left hand side). The acceptance ratio is calculated per temperature level, which means that there are 50 feasible neighbor solutions. Neighbor solutions that are better or equal are not taken into account for this ratio, since they are always accepted.

$$\text{Acceptance ratio} = \frac{\text{Accepted worse solutions}}{\text{Accepted worse solutions} + \text{Not accepted worse solutions}}$$

The curve in Figure 5.4 shows similarities with the curve in Figure 3.3. We see that with a high temperature, the acceptance ratio is 1 or almost 1. When the temperature cools down, the ratio decreases and at the end the probability of accepting a worse solution is equal to 0.

Figure 5.5 shows the costs curve for experiment 4. The most left point is the performance of the initial solution. With this solution, we look for neighbor solutions. We see that the performance increases and decreases very often, from about one-third of the figure, we see more increases than decreases (since we want to minimize the performance, the costs should be as low as

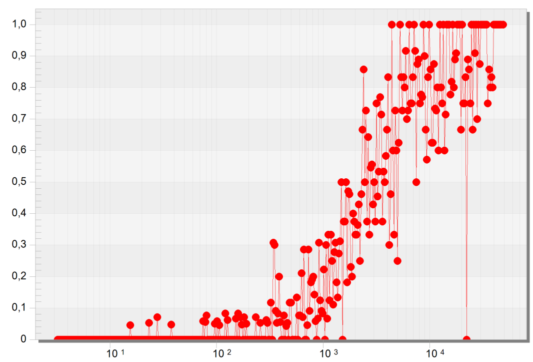


Figure 5.4: Acceptance ratio 'Time not in TW'

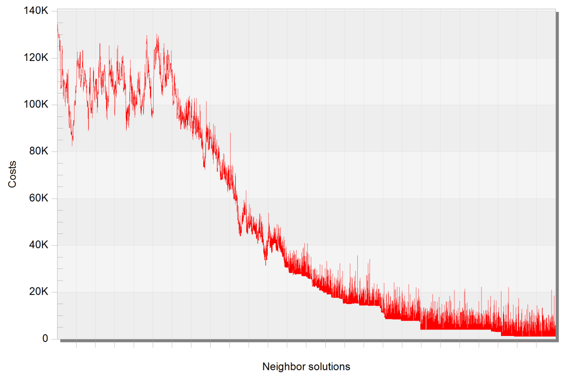


Figure 5.5: Performance curve of 'Time not in TW'

possible). This is also caused by the decreasing temperature, since less worse solutions are accepted. At the end, the best solution is not improved anymore, which means that we found a local optimum. The same experiments should run more often, in which the choices for the improvement operator differ per iteration, which may result in better solutions.

Based on this results, we conclude that the start and stop temperature and the cooling factor are set well, such that there are enough iterations to find a good solution. In the same way, this is done for the other KPIs. The results can be found in Appendix J.

5.4 Results of experiments

The key performance indicators that are used to evaluate the results are:

- Not in time
- Time too late
- Not in TW
- Time not in TW
- Number of trucks
- Travel time
- Waiting time
- Number of detours
- Detour time

The results are presented below in graphs. We consider four scenarios, which are the original scenario, no decoupling, all decoupling, and no loading/discharge time. The bars in the figures correspond to one of the scenarios, which is explained in the legend above the figure. The experiments are divided in groups as mentioned in Section 5.2. Each of the figures present one key performance indicator. Experiments B1 and B2 are the benchmark scenarios, which are the results of the construction phase with sorting jobs randomly respectively on latest departure time.

5.4.1 Optimization goal

The optimization goals differ in this set of experiments. We need to scale the differences 'costs' for these experiments, because the total number of trucks is a lot smaller than the total travel time in seconds. Because of these differences, the start and stop temperature differ per experiment. Table 5.8 shows the experiments as a recap.

Table 5.8: Experiments for optimization goal

Exp.	Optimization goal	Cooling factor	Start temperature	Stop temperature
1	Not in time	0.975	100	0.1
2	Time too late	0.975	50000	10
3	Not in soft time window	0.975	100	0.01
4	Time outside soft time window	0.975	50000	10
5	Total trucks	0.99	10	0.1
6	Total travel time	0.975	100000	5000
7	Total waiting	0.975	100000	10
8	Total detours	0.95	1000	1
9	Total time detours	0.975	50000	100

Figures 5.6 to 5.14 show the results of experiments.

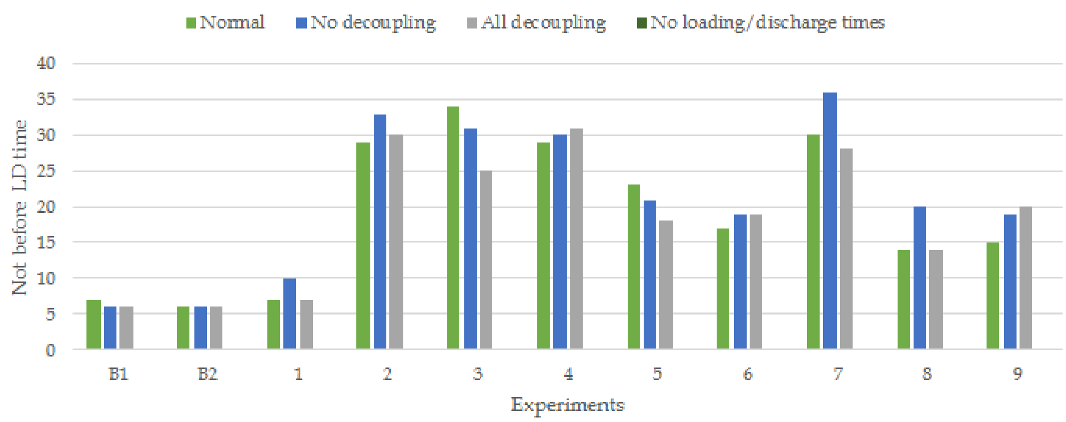


Figure 5.6: Number of containers after loading/discharge time

Experiments 1 and 2 optimize respectively the number and the time that the containers are delivered later than the LD time. Figures 5.6 and 5.7 show that optimizing the number of containers in time (Exp. 1) performs worse than the best benchmark case. Optimizing the lateness of the containers (Exp. 2) performs bad. Furthermore we see that there is no experiment in which the total time too late is equal to zero. There are six containers for which the LD time is earlier than the start time plus the travel time. It is therefore, for this situation, not possible to have 0 containers too late or a lateness of 0 minutes.

Experiments 3 and 4 focus on the soft TWs. Compared to a single time point, the LD time, there are more containers that are not delivered in the soft TW. When containers are delivered early,

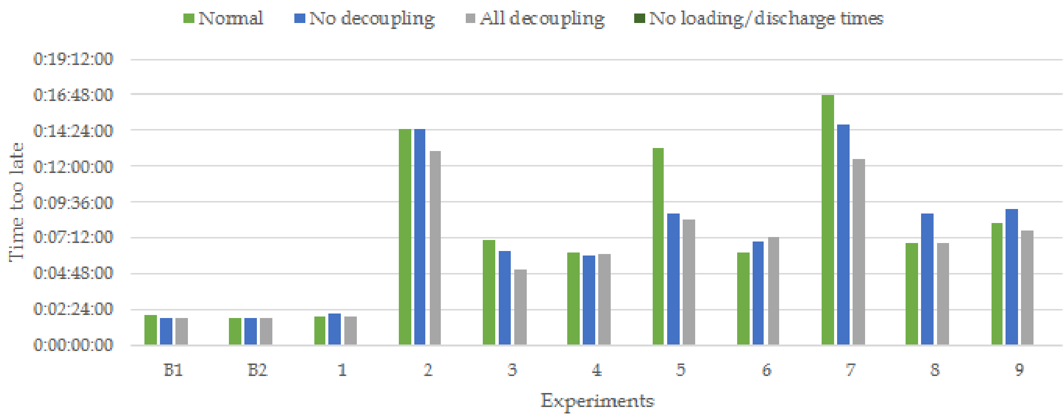


Figure 5.7: Total time of containers that are delivered after the loading/discharge time

these are in time for the LD time optimization goal. But if the containers are very early, before the soft TW starts, the containers are not counted as in time for the soft TW. The other way around, optimizing the number of containers in the soft TW (Exp. 3) results in 34 containers that are delivered after the LD time. Experiments with the length of time windows (Exp. 14 to 18) further researches the role of a time window.

Optimizing the waiting time (Exp. 7) results in many containers that are delivered too late (Figure 5.6) and a high lateness (Figure 5.7). A trucks needs to wait at least until the start of the hard TW, which is in these experiments a period of 2 hours instead of 40 minutes. The difference of these two different periods results in a worse performance for the soft TW related performance indicator. Experiments (Exp. 14 to 18) continue on the role of the hard and soft TW.

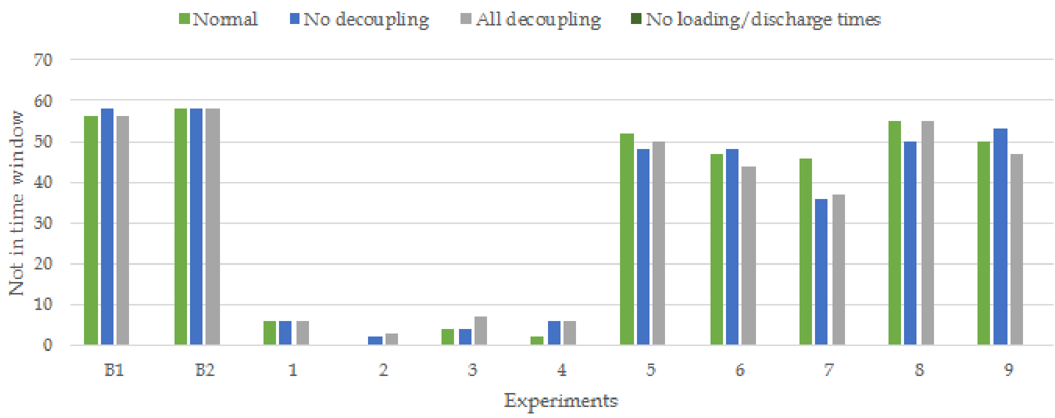


Figure 5.8: Number of containers delivered outside time window

Figure 5.8 and 5.9 show the TW related KPIs. We see that the timeliness related KPIs perform much better than the costs related KPIs. The benchmark scenarios for ‘Not in time window’ perform worse than all other experiments, but this is not true for the ‘Total time outside TW’ KPI. The number of trucks outside the time window can be reduced from almost 60 jobs to around 5 jobs, with the timeliness related KPIs.

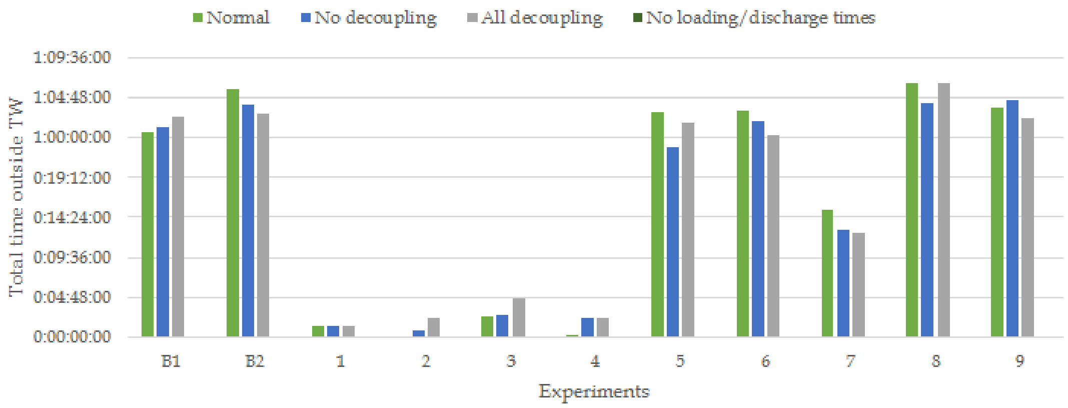


Figure 5.9: Total time of containers that are delivered outside time window

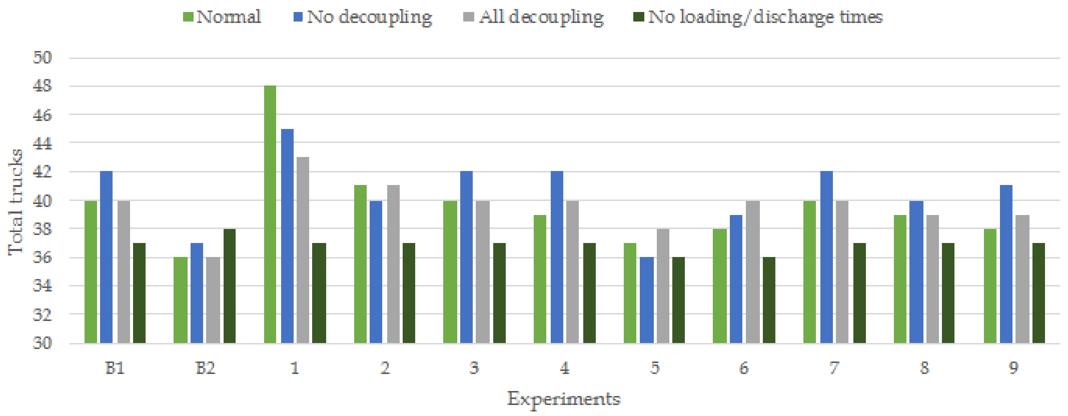


Figure 5.10: Total number of trucks

Figure 5.10 shows the number of trucks. Experiment 5 results in the best performance with in total 36 trucks, which is as expected, because the optimization goal is to minimize the number of trucks. However, the second benchmark case also performs well, with at most one truck different from experiment 5. Optimizing the total travel time (Exp. 6), number of detours (Exp. 8), and time of detours (Exp. 9) also result in less trucks compared to the benchmark case B1. This can be explained, because there is a limited amount of time per truck and minimizing the travel and detour time results in less trucks needed comapred to the first benchmark scenario. The second benchmark scenario performs better than the first benchmark scenario and almost all other experiments, except experiment 5 and for the no LD times scenario.

Figure 5.11 shows the KPI 'Travel time'. The somewhat bigger difference for the benchmark experiments in the 'No LD times' scenario compared to the other three scenarios is because the jobs cannot be sorted on 'Latest departure time', because there is no LD time. In almost all experiments, the total travel time for the 'All decoupling' scenario is higher than the other scenarios, because there are more jobs. Optimizing the travel time (Exp. 6) or detour time (Exp. 9) results in the best performance in terms of travel times. The benchmark scnearios have a travel time of about 8 days, and the best experiments about 6 days. Except the 'No decoupling scenario', the optimization of detour time results in less travel time than directly optimizing the

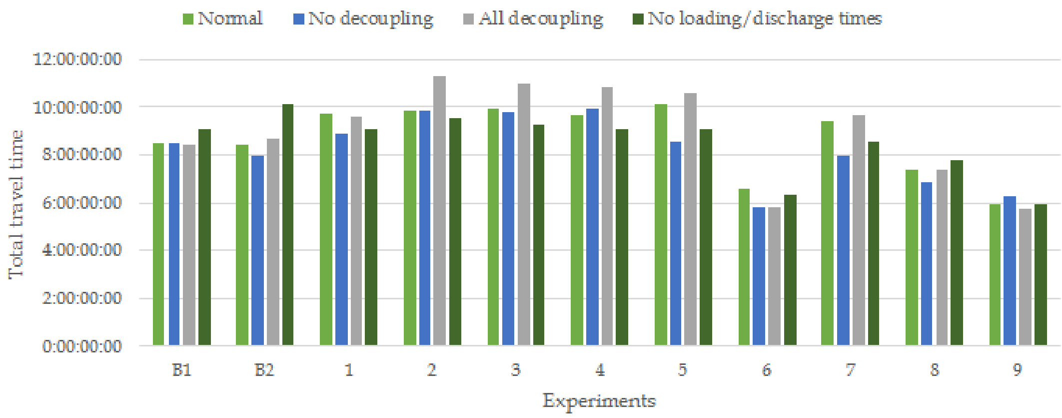


Figure 5.11: Total travel time of all trucks

travel time. However, the differences are small and may be the result of the different start and stop temperatures. Running more replications, for different days, or running the experiment for a longer time, should make clear if this is coincidence, or that this is valid in all scenarios.

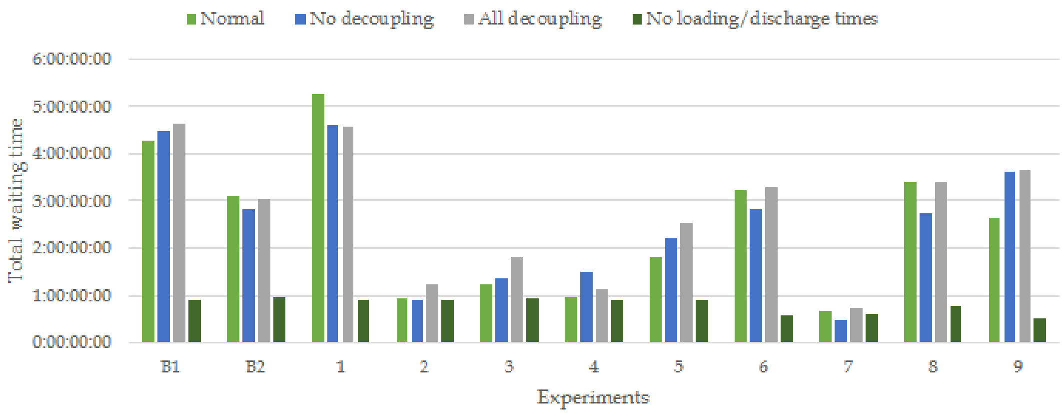


Figure 5.12: Total waiting time of all trucks

Figure 5.12 shows the total waiting time of all trucks. Waiting time involves waiting for the start of the hard time window, but also a break after 4.5 hours of driving for 45 minutes. The waiting time in the 'No LD times' scenario is therefore only due to breaks of truck drivers. Theoretically, the waiting time can only be zero, if none of the truck drivers drive for more than 4.5 hours. This is practically not possible, because besides the length of a job itself, the truck should start and end at an inland terminal, and this already takes more than 4.5 hours for some of the jobs.

The total waiting time performs bad in the benchmark scenarios, because once a job is chosen, it is forced to wait until the hard time window starts. Nevertheless, sorting on latest departure time (Exp. B2) reduces the total waiting time compared to randomly choosing a job (Exp. B1). It is not possible to do a job in the time that a truck is waiting, such that the total waiting time is used in a good way.

The effect of the improvement phase is very clear for this KPI, because the performance is better in almost all other scenarios and experiments, except experiment 1 (minimizing number of trucks after LD time). The experiments that performs best in all scenarios is in which the total waiting time is minimized, which is as expected. Also experiments 2, 3 and 4 perform well, which is logical, because they are related to the time too late and the soft TWs. The best reduction is from almost 3 days in the second benchmark case to about 0.5 days with optimizing 'Waiting time'.

Minimizing the travel time (Exp. 6), number of detours (Exp. 8), or time of detours (Exp. 9) results in a bad performance for waiting time, but still perform better than the benchmark scenarios.

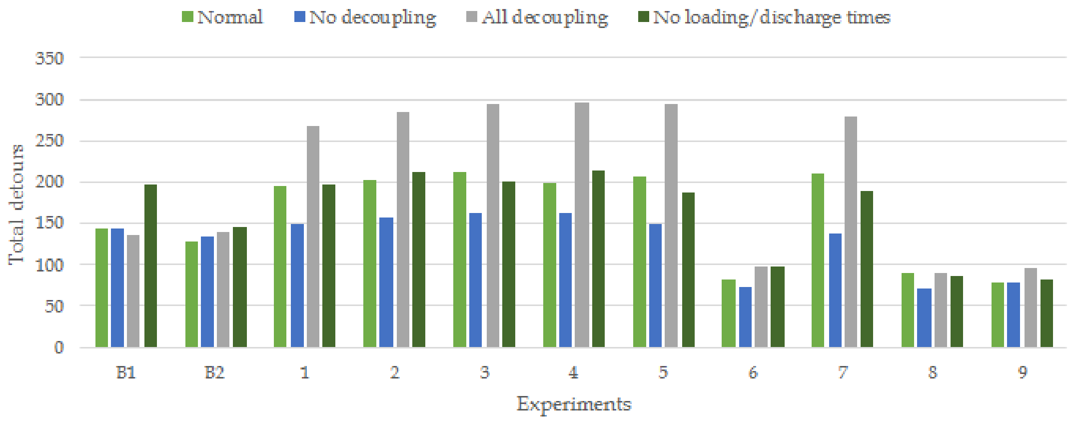


Figure 5.13: Total number of detours of all trucks

The results for performance of the number of detours in Figure 5.13 can be split up in two groups of experiments with similar results. Minimizing travel time (Exp. 6), number of detours (Exp. 8), and detour time (Exp. 9) perfors well, but time related KPIs perform bad and also even worse than the benchmark situations. This is logical, because detours are needed to arrive at the LD address in time. The experiments also show that in the 'All decoupling' scenario there are more detours compared to the normal and no decoupling scenario. This indicates that if there are more jobs to do, that there are also more detours. This should of course not always be the case, because it is also possible to wait at the LD address. The experiments do not take into account this flexibility, because this also results in different service times. Further research should incorporate this possibility.

As last key performance indicator we have the total time of detours in Figure 5.14. The performances are similarly to the number of detours, but there are some small differences. The benchmark cases score better than all scenarios of experiments for experiment 1 to 5, and two of the scenarios of experiment 7. The benchmark case selects the truck for which the job arrives as first and so minimizes the detour and length of detour. In the other experiments, minimizing the detour time is not related with the optimization goal of the experiment, for example, optimizing timeliness.

Experiments 6 and 9, which optimize the waiting time and the detour time, perform the best, followed by experiment 8, which optimized the number of detours.

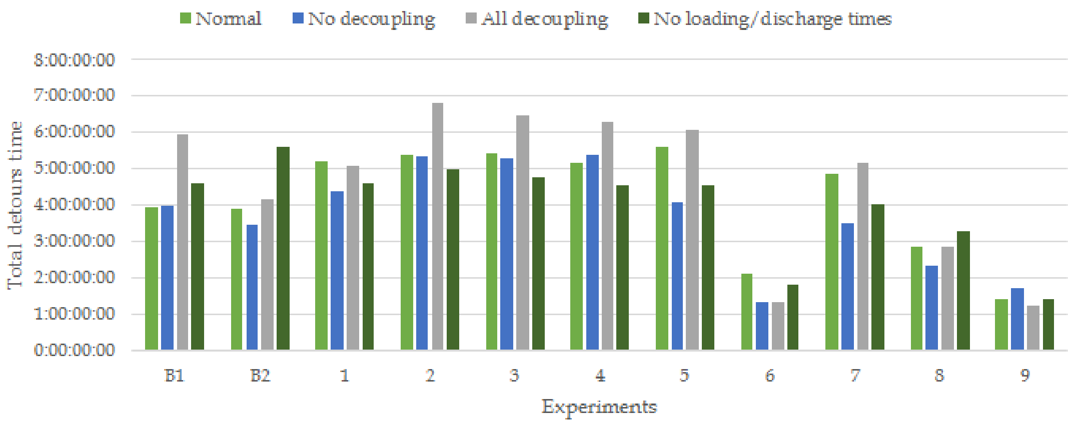


Figure 5.14: Total time of detours of all trucks

5.4.2 Discussion optimization goal

The key performance indicators in Figures 5.6 and 5.9 above are related to timeliness at the customer. Delivering the containers in time at the customer results in satisfaction at the customers and reliability for CTT. This is important for CTT, but costs are also important. There is no KPI in this research that measures costs in terms of euros. Nevertheless, optimizing the KPIs mentioned in Figure 5.10 to 5.14 results in less costs in terms of euros. For the total number of trucks, these are fixed costs for purchasing a truck, but also variable costs for maintenance. The costs for travel time can be expressed in fuel and labor costs. Labor costs are involved in the KPI for waiting time and detour time. Finally, fuel costs are related as well to detour time. The ideal situation comprises the lowest costs with the highest satisfaction at customers, or a good balance between these two groups of KPIs. The differences between the types of KPIs can be seen clearly in Figures 5.8 and 5.9.

The optimization goals lead to different ranges of costs. The total number of trucks lies between 36 and 42, but the total travel time differs from almost 6 days, to almost 11 days. This difference is even much bigger, because the time is measured in seconds. It is therefore necessary to scale the parameters by means of the start and stop temperature. This may result in different acceptance probabilities. Nevertheless, the acceptance fractions for the different experiments look similar.

Figure 5.15 presents the numerical values of the experiments in the normal scenario, and also the experiments that we will describe next. Red cells represents a bad performance for that KPI, green cells represents the best performances, and the white cells are in between. Figure 5.15 can be used to assess the overall performance of an experiment. For example, we can see clearly that experiment 1 (time too late) performs well on 'Not in time' and 'Time too late', but bad at 'Not in TW' and 'Time not in TW'. Experiment 4 (time not in TW) performs average or better on all KPIs and experiment 2 performs bad or at most average on the KPIs. Therefore we may conclude that the settings of experiment 4 are better than experiment 2, but we should be careful because of the different start and stop temperatures.

Appendix K describes the numerical results of the other three scenarios.

	Not in time	Time too late	Not in TW	Time not in TW	Number of trucks	Travel time	Waiting time	Number of detours	Detour time
B1	7	0:02:03:25	56	1:00:34:05	40	8:11:16:50	4:06:23:39	143	3:22:39:01
B2	6	0:01:51:18	58	1:05:43:50	36	8:10:19:51	3:02:18:41	129	3:21:42:02
1	6	0:03:01:14	52	1:05:31:04	39	9:15:17:26	2:20:12:50	212	5:02:39:37
2	6	0:01:51:18	51	1:06:01:47	40	9:00:50:57	3:01:57:50	198	4:12:13:08
3	34	0:07:03:40	4	0:02:24:13	40	9:22:34:05	1:05:42:12	212	5:09:56:16
4	29	0:06:13:07	2	0:00:18:49	39	9:15:43:57	0:23:15:00	198	5:03:06:08
5	23	0:13:15:06	52	1:03:00:02	37	10:02:54:40	1:19:50:56	206	5:14:16:51
6	17	0:06:14:32	47	1:03:16:57	38	6:14:25:12	3:05:15:40	82	2:01:47:23
7	30	0:16:49:37	46	0:15:13:15	40	9:09:25:35	0:16:34:15	211	4:20:47:46
8	14	0:06:53:31	55	1:06:30:25	39	7:08:21:24	3:09:31:44	90	2:19:43:35
9	15	0:08:14:31	50	1:03:32:44	38	5:21:49:54	2:14:59:13	78	1:09:12:05
10	29	0:05:49:20	5	0:01:54:28	40	9:21:52:14	1:04:52:55	210	5:09:14:25
11	27	0:05:40:06	14	0:03:04:46	40	9:20:11:09	1:01:38:37	201	5:07:33:20
12	33	0:06:23:29	8	0:03:51:57	40	9:19:25:57	1:10:34:10	210	5:06:48:08
13	31	0:06:15:36	5	0:01:57:07	40	10:01:10:00	1:03:48:59	204	5:12:32:11
14	11	0:02:27:50	0	0:00:00:00	43	10:13:01:03	3:10:14:56	215	6:00:23:14
15	25	0:02:47:52	25	0:03:19:27	46	10:11:30:30	1:21:10:37	198	5:22:52:41
16	7	0:01:55:05	6	0:01:21:18	48	9:17:34:38	5:06:19:03	196	5:04:56:49
17	29	0:14:32:02	0	0:00:00:00	41	9:21:30:09	0:22:30:00	202	5:08:52:20
18	17	0:06:47:40	0	0:00:00:00	40	9:19:28:49	2:02:23:35	198	5:06:51:00
19	28	0:05:01:37	3	0:01:03:09	40	9:20:47:40	1:02:14:44	209	5:08:09:51
20	34	0:06:36:22	2	0:00:40:26	40	10:11:17:33	1:03:17:06	209	5:22:39:44
21	28	0:05:01:37	3	0:01:03:09	40	9:20:47:40	1:02:14:44	209	5:08:09:51

Figure 5.15: Results normal scenario

5.5 Sensitivity analyses

This section analyzes the settings of the experimental factors in the simulated annealing algorithm.

Improvement operator

This section analyzes the role of the improvement operators in the simulated annealing algorithm. In the standard situation (experiment 4), the probabilities to move, swap, or cross are respectively 0.33, 0.34, and 0.33. Experiment 10 only uses crossing as operator, experiment 11 only swapping, and experiment 12 only moving. All other parameters are equal. We look specifically at the time of delivery outside the time window, since this is the optimization goal for the three experiments. In these experiments, we start with a sequence of 3 jobs, then 2 jobs, and then 1 job. Experiment 13 always takes 1 job for the operator, and the probabilities are the same as in experiment 4. Figure 5.16 shows the results of the experiments.

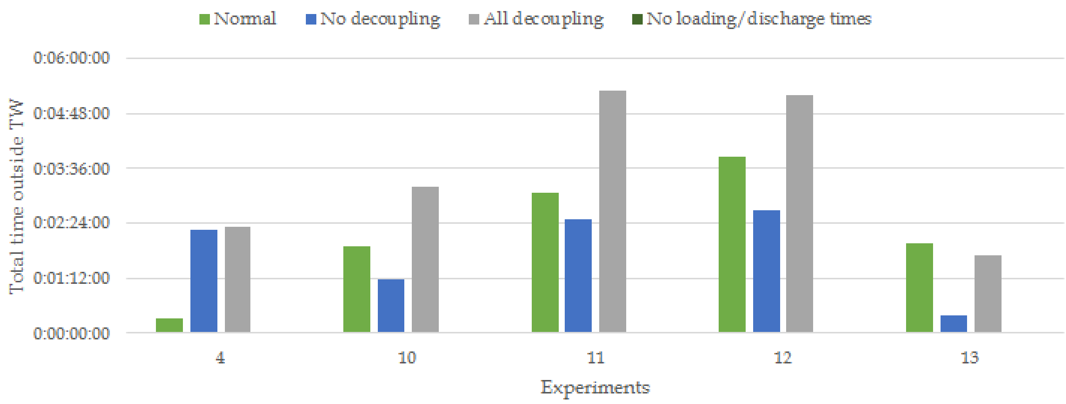


Figure 5.16: Total time of containers that are delivered outside time window with different improvement operators

For the first set of experiments, where the sequence of jobs varies from 3 to 2 to 1, the combination of all three improvement operators performs better than using one improvement operator, except the 'No decoupling' scenario with only crossing. Therefore, based on this results, we may conclude that a combination of all improvement operators performs better than using one of the improvement operator. However, experiment 13, where only sequences of 1 job are used for the operator, performs better, except in the 'Normal' scenario.

Time windows

The experiments with different time windows are mentioned in 5.9 as a recap. Figure 5.17 shows the results of the experiments.

Table 5.9: Experiments for time windows

Exp.	Soft time window	Hard time windows	Decoupling
4	20 minutes before and after LD time	1 hour before and after LD time	Customer dependent
14	20 minutes before and after LD time	20 minutes before and after LD time	Customer dependent
15	5 minutes before and after LD time	15 minutes before and after LD time	Customer dependent
16	5 minutes before and after LD time	5 minutes before and after LD time	Customer dependent
17	1 hour before and after LD time	3 hour before and after LD time	Customer dependent
18	1 hour before and after LD time	1 hour before and after LD time	Customer dependent

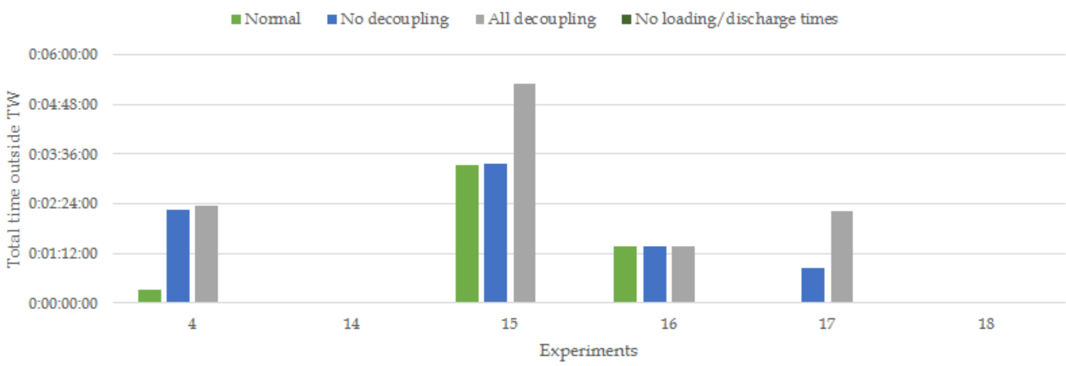


Figure 5.17: Total time of containers that are delivered outside time window with different time windows

What we see is that it is possible to deliver all container within a time window of 20 minutes before and after the LD time, because we see that in experiment 14 there are no containers delivered too late. This does not hold for a soft time window of 10 minutes in total, because this is too small time period for the earliest jobs on a day. We see in the two hour time window case that it is for the normal scenario possible to deliver all containers within the time window. Nevertheless, the time outside the time window is at most 2.5 hours for all jobs together.

Stop criterion

The stop criterion influences the running time of the algorithm, and therefore the probability to find the best solution. Nevertheless, running for a long time will not always yield a better performance.

Exp.	Stop criterion
2	Stop temperature and number of improvements
19	Stop temperature
20	Number of improvements
21	Stop temperature or number of improvements

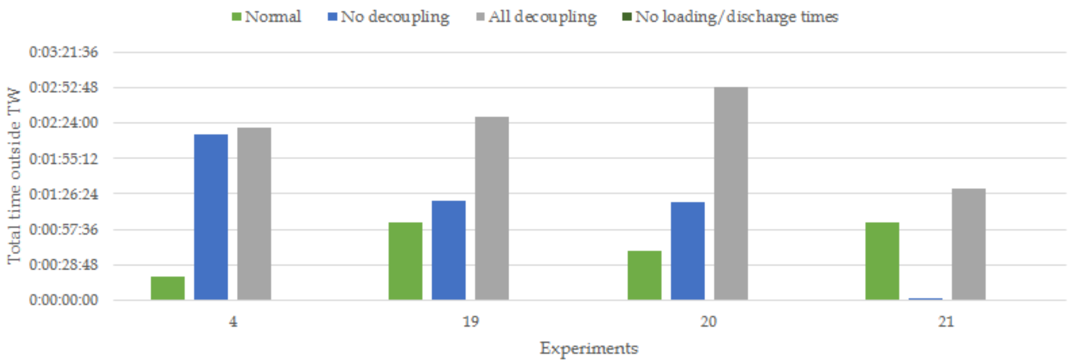


Figure 5.18: Total time of containers that are delivered outside time window with different time windows

Figure 5.18 shows the results for different stop criteria. We see that, compared to the normal situation, only a stop temperature yields worse performance for the 'Total time outside TW'. When the stop criterion is the number of temperature levels without improvement (Exp. 20), we have a better performance in the 'No decoupling' scenario, but not in the other two scenarios.

5.6 Conclusions of solution tests

This section answered the research question 'What are the best settings to improve the performance with using decision support for container transport scheduling?' Section 4.3 described solution model we test this model in this chapter.

- Section 5.1 described the experimental set-up that we use to test the solution methods. This involves the assumptions, experimental factors and the planning scenarios. We test different optimization goals, initial solutions, improvement operators, and stop criteria. Each experiment is tested on four planning scenarios, which disable or force decoupling at customers, where there are no loading/discharge times, and the original situation. The data is gathered from CTT.
- Section 5.2 described the experiments. Not all combinations of experimental factors and planning scenarios are tested, because this is too time consuming.
- Section 5.3 verified the model and the settings of start an stop temperature and the cooling factor, by using the acceptance ratio and the performance curve.
- Section 5.4 showed the results of the experiments. The benchmark situations perform well for the loading/discharge time related KPIs. The difference between timeliness and costs related KPIs is clear in the time window related KPIs, in which the number of missed time windows decreases from about 55 to around 5. For the minimization of the number of trucks, the benchmark situation performs better than minimization of trucks optimization goal. The best results is 36 trucks in the benchmark case, and 37 when minimizing the trucks. The worst performance is when we optimize the total number of containers before the LD time, because there are 48 to deliver the containers in time. Minimizing the total travel time can be done by minimizing the travel time or minimizing the total time of

detours, which results in about 6.5 and 7 days of travelling, compared to almost 8.5 days in the best benchmark case. For the waiting time we can also optimize 'Time after LD time' or the time window related KPIs, but the minimization of waiting time still performs the best as expected. The total waiting time can be reduced from 3 days in the best benchmark case to about 16 hours in the normal situation. Reducing the number of detours and time of detours can be done best by reducing the time of detours. This reduces the number of detours from 129 to 78, and the time of detours from almost four days to almost 1.5 days. The results of these experiments should be further researched, because there are different temperatures used for the experiments, which means that there are different acceptance ratios.

- Section 5.5 test different settings of parameters. We see that only crossing of routes performs better than only moving or swapping jobs. A sequence of one job all the time performs better than changing from 3 to 2 to 1 using the Or-opt operator. Nevertheless, a combination of crossing, moving, and swapping performs the best in almost all situations. It is possible to deliver all jobs within a time window of 20 minutes before and after the LD time, but not within a 10 minutes time window. We see that, compared to the normal situation, only a stop temperature yields worse performance for the 'Total time outside TW' compared to the where both stop criteria should be true.

Chapter 6

Conclusions and discussion

> "All models are wrong, but some are useful"
>
> Box and Draper (1987)

The quote above illustrates the difficulties when building a model, which is a simplified realisation of the complex reality. In the same way, assumptions are used in the solution method and thus influence the results. This chapter discusses the results and the relevance of the results compared with the complex reality of truck scheduling. We start the chapter with the conclusions of this research in Section 6.1. Section 6.2 describes the limitations of the model. Section 6.3 addresses recommendations for CTT and for related problems. This chapter ends in Section 6.4 with suggestions for further research.

6.1 Conclusions

This chapter summarizes the answers to the research question and the sub questions. The research goal of this thesis is to give support to the truck planners for container transport to improve the performance. Four research questions helped us to achieve this goal.

Chapter 2 described the context analysis. The container (transport) sector is growing from year to year, and this also influences the transport of containers in the hinterland. CTT faces this growth and the main problem is that it is difficult for the truck planners to use all this information of containers and bookings in their advantage. In an ideal situation, this information leads to a synchromodal network, in which the synchronization of information leads to better use of the modalities barge, train, and truck. The planning and scheduling for the modalities is done separately at CTT, but they need information of each other. Decisions regarding the allocation of containers to the barge or train influences the truck scheduling, but it is not clear for the barge and train planners what the consequences are of this decision. This may result in additional travel time and also that other containers are too late at the customer or sea terminal. Decision support can help to give insight in the network, such that these situations are made insightful.

We reviewed the literature about container transport in Chapter 3, and in particular focused on truck scheduling. The literature described the problem as a vehicle routing problem, but there is not a single type of vehicle routing problem which fully describes the complex situation at CTT. A classification scheme helped to describe the problem and we concluded that the problem at CTT has the following characteristics of a VRP:

- Vehicles with fixed capacities
- Heterogeneous fleet
- Time windows at customers, terminals and for resources
- Pick up and delivery
- Release and due dates
- Multi-depot
- Full truck load

The chapter continued to find a solution method for this problem. We searched for a heuristic, because heuristics are able to find good solutions in an acceptable amount of time. Simulated annealing turned out to be most applicable, because it is able to escape from local optima and does not have to calculate the performances of all its neighbors like in tabu-search. The heuristic comprises a construction phase and an improvement phase. In the first phase, the output is an initial truck schedule for one day. In the second phase, jobs are moved and swapped between trucks, aiming to find a schedule better than the initial schedule. The characteristic of simulated annealing is that it sometimes also accepts worse schedules than the current schedule, with a higher purpose to find a better solution at the end. Chapter 3 concluded with literature about implementing decision support. When our model is ready, validated, and verified, this does not necessarily mean that it will be accepted by the employees. The decision support system must at least fulfill three requirements, it should be: realistic and efficient, inexpensive to acquire and to modify, and easy to use and enhance the job.

Chapter 4 described the solution method. The chapter started with some use cases at CTT, which should be avoided in the future by using our decisions support methods. The most important and easiest, is the merging of a delivery and a pick up job, at locations nearby. This combination replaces two empty trips, one to each of the customers, by one trip from the delivery customer to the pick up customer.

The chapter continued with the solution methods for the different functionalities of a future decisions support system. The following functionalities are described:

- Scheduling based on departure time
- Calculate number of trucks needed
- Offline scheduling
- Online scheduling
- Synchromodal scheduling

Chapter 5 test the solution methods of Chapter 4. The focus in the experiments is on offline scheduling, which produces an initial schedule for one day. The key performance indicators are customer related (focus on timeliness) or related to CTT (total travel time, number of trucks, detours, and waiting time). The experiments focus on four different scenarios. The first scenario is the original scenario at CTT at one day. The second scenario is adjusted such that there is no decoupling allowed at any of the customers. The third scenario forces to decouple at the customer, if possible. The fourth scenario has no loading/discharge times. Different settings for the simulated annealing heuristic are tested to find the best settings in each scenario.

The results of the experiments are also presented in Chapter 5. There are two benchmark situations used. The first one is the result of the construction phase, where the jobs are chosen randomly and then allocated to the truck with which the job arrives as first. The second benchmark first sorts the jobs on latest departure time.

The benchmark situations perform well for the loading/discharge time related KPIs. The difference between timeliness and costs related KPIs is clear in the time window related KPIs, in which the number of missed time windows decreases from about 55 to around 5. For the minimization of the number of trucks, the benchmark situation performs better than minimization of trucks optimization goal. The best results is 36 trucks in the benchmark case, and 37 when minimizing the trucks. The worst performance is when we optimize the total number of containers before the LD time, because there are 48 to deliver the containers in time. Minimizing the total travel time can be done by minimizing the travel time or minimizing the total time of detours, which results in about 6.5 and 7 days of travelling, compared to almost 8.5 days in the best benchmark case. For the waiting time we can also optimize 'Time after LD time' or the time window related KPIs, but the minimization of waiting time still performs the best as expected. The total waiting time can be reduced from 3 days in the best benchmark case to about 16 hours in the normal situation. Reducing the number of detours and time of detours can be done best by reducing the time of detours. This reduces the number of detours from 129 to 78, and the time of detours from almost four days to almost 1.5 days.

So, for most KPIs, our proposed model performs better than the benchmark scenarios, except from the total number of trucks. This may be interesting in practise, when the total number of trucks available is limited. For the other KPI we suggest to use the model of this thesis.

The main research question of this thesis was: 'How can we give decision support to CTT's truck planners to improve the performance of timeliness and costs of container transport per truck?'. This research shows that our model is able to improve the performance of container transport compared to the benchmark scenarios.

6.2 Limitations

This research is limited by the complexity of the problem and the amount of time available. Assumptions are made to simplify the problem, but this also means that the results of the model should be handled with care. This section describes the consequences of the assumptions and how this should be taken care of.

Limitations related to assumptions

We made assumptions for the conceptual model. To start with, the model allows at most one container per truck at a time. In reality, it is also possible, and usual, to transport two TEU on a 40 feet chassis. This has positive consequences, because the trucks can be used more efficiently and also travel time will reduce.

Second, the model assumes that a chassis is fixed per truck for a day and always available. In reality, there is a limit on the number of chassis available. Truck drivers can change the chassis if they need a larger one, but this takes time. It is difficult to say in what way this assumption influences the results in reality. On one side, if there is a chassis for each truck available at the beginning of the day, this will also be the case for the remaining of the day, because the model assumes that all containers at one truck have the same length. On the other side, if there are too many chassis at customers, it is possible that not all containers can be transported at the beginning of the day, because there are not enough chassis available for the trucks. These containers have to wait until the chassis are returned. Besides, the height of a container also influences the chassis, because some higher containers need a low chassis. The effect of the chassis needs to be tested in further research.

The third limitation is the availability of truck drivers. The model assumes that all trucks excluding the chassis, are the same. This means that all truck drivers can transport all type of containers and chassis, start at the same time and are available during the same time period, and all drive at the same speed. In reality, not all truck drivers are allowed to transport dangerous goods or drive with extra long chassis. Also, not all truck drivers start at the same time, and work the same amount of time per day. Driving regulations state that truck drivers should rest after 4.5 hours of driving for at least 45 minutes. Besides this rule, there are more regulations to take into account, but are difficult to incorporate in a model with a planning horizon of one day. The limitations related to truck drivers influence the results, but can be incorporated in an extended model. The model already uses 'special trucks', the sideloader and lifting chassis. In the same way, this can be extended to groups of trucks with dangerous goods. This means that containers with dangerous goods may only be assigned to this kind of special trucks and therefore licensed truck drivers.

The fourth limitation is the horizon of one day. In the previous limitation we already named the EU driving regulations, but there is another limitation. The demand for containers is not always restricted to one specific day. It is possible in some cases to transport a container the day before the loading/discharge date. This is especially interesting when the loading/discharge time is in the early morning, which is the busiest moment. The input in the model for this research are all containers with a gate in or gate out on the specific day. 'Smarter' decisions to transport a container the day before are not possible in this model.

Limitations related to implementation of the model

This section describes the limitations related to the implementation of the model. As discussed in the literature review on implementing decision support, it may lead to difficulties when we want to implement and adapt to a new system. Moreover, to produce a truck schedule with the current tools, the following software packages are used: Modality, MySQL, Microsoft Excel, Google Maps. Siemens Plant Simulation is used as the programming language. A comprehensive guide might help, but this does not take away all the manual steps.

The model in the current state is not useful for CTT. Nevertheless, additional improvements can make the model useful. The biggest weakness is that the input for the model is hard to gain. First, this is caused by the number of software programs that is used as mentioned above. Second, it takes time to import the data and related to this; third, the changes during the day in resources and demand force to update the data very often, but this cannot be achieved with the current model. We must note that this is only relevant when we need an online schedule. However, an offline schedule can be made the day before, but the risk is that the input data for that schedule, has been changed during the night. Furthermore, the truck planners need to be instructed about the use of this solution method.

6.3 Recommendations

We recommended first to implement a procedure to determine the latest departure time for a container to make the planner's task easier. This is the loading/discharge time minus the travel and decoupling time. First, this can be done by using Google Maps, but later on, it should be possible to extract this data from Carrierweb[1].

Furthermore, the suggestions mentioned in the limitations section, should be implemented in the model. Moreover, more data about the truck drivers is necessary, for example working hours, licenses to transport specific containers, and also preferences for specific routes if possible.

In general, the data used such as loading/discharge times, average speeds, travel times, working hours, and so forth, are all averages and based on assumptions. The model is ready to be updated with new data and so we recommend this to do before implementation and further testing.

Nevertheless, the model is able to cope with many situations. Running the method several times produces different schedules. These schedules can be given to the truck planners, so the truck planners decides which schedule they want to use. In an ideal situation, the truck planner points out why he prefers a specific schedule over another one, so that this information can be incorporated in a new version of the model. The main drawback of the current method is the changing nature of its input requirements. Resources and demand change during the day, which means that new information emerges very often. A real life connection between Modality and the solution method is of high importance when we want to use the method for online scheduling

[1]Carrierweb enables trucking companies to communicate with the truck drivers, but also retrieves data as GPS coordinates and driving statistics as speed, emission, and number of breaks

6.4 Further research

This research gave insight in the complex reality of truck scheduling. Many assumptions are incorporated in the model. Some of these assumptions need further research, as mentioned before in the recommendations, but the model is able to produce schedule with a better performance than the benchmark scenarios. A proposed extended version of the current model should be able to change the inland terminal from Hengelo to Bad Bentheim for example, to force the container to be transported by train instead of barge. When this improves the performance, this change should be accepted. Further research should investigate how this model can be extended to have the barge and train as modalities as well and with flexible destinations of a container.

Furthermore, it might be interesting to research the possibilities where there are no loading/discharge times at the customers. Customers will be informed one hour before the container arrives and are able to follow the container via GPS coordinates, for example. This increases the flexibility at CTT. This flexibility from the customers may be rewarded with a discount. This is especially interesting in the early morning, which is the busiest moment at CTT.

Even so, decisions about the transport date of a container should be included. The current model considers a historical data set as input for the model, but in reality, we need data, which may change during the day. We may decide to transport a container one day in advance, if we have enough resources on that day and the customer agrees with this.

As last, we suggest to research the tasks of human planners and whether they can be partly automated. Of course, there are always special situations which need the knowledge of human planners, but most of the decisions should be possible to automate. If this is researched further, the step to synchromodal transport becomes smaller.

In a broader scope, this research is interesting for Synchromodal-IT and the Port of Twente. The combination of the different projects where CTT works with, give the opportunity to work together to get even more information about containers, transport possibilities, and demand of customers. This research showed that information overload is not a problem, but a possibility to improve the performance of container transport.

References

Alfa, A. S., Heragu, S. S., & Chen, M. (1991). A 3-opt based simulated annealing algorithm for vehicle routing problems. *Computers & Industrial Engineering*, *21*(1), 635–639.

Altinkemer, K., & Gavish, B. (1991). Parallel savings based heuristics for the delivery problem. *Operations Research*, *39*(3), 456–469.

Baker, B. M., & Ayechew, M. (2003). A genetic algorithm for the vehicle routing problem. *Computers & Operations Research*, *30*(5), 787–800.

Beasley, J. E. (1983). Route first—cluster second methods for vehicle routing. *Omega*, *11*(4), 403–408.

Beck, J. C., Prosser, P., & Selensky, E. (2003). Vehicle routing and job shop scheduling: What's the difference? In *Icaps* (pp. 267–276).

Bell, J., & McMullen, P. (2004). Ant colony optimization techniques for the vehicle routing problem. *Advanced Engineering Informatics*, *18*(1), 41-48. (cited By 239) doi: 10.1016/j.aei.2004.07.001

Bontekoning, Y., Macharis, C., & Trip, J. (2004). Is a new applied transportation research field emerging?—a review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice*, *38*(1), 1 - 34. doi: http://dx.doi.org/10.1016/j.tra.2003.06.001

Box, G. E. P., & Draper, N. R. (1987). Empirical model building and response surfaces. , 1472–1483.

Braekers, K., Caris, A., & Janssens, G. K. (2013). Integrated planning of loaded and empty container movements. *OR spectrum*, *35*(2), 457–478.

Bruining, E., van Aggelen, J., & Muller, D. (2015). *BIT BV Opdracht 2015.*

Buck Consultant International - Kees Verweij. (2015). *Synchromodal transport. opportunities for entrepeuneurs in north-western europe.* Retrieved 2015-07-28, from `http://www.slideshare.net/keesverweij/bci-kees-verweij-dinalog-congress-synchromodal-presentation-march-31-2014`

Caris, A., Macharis, C., & Janssens, G. K. (2013). Decision support in intermodal transport: A new research agenda. *Computers in Industry*, *64*(2), 105–112.

Cerny, V. (1985). Optimization by simulated annealing. *A thermodynamical approach to the travelling salesman problem: an efficient simulation algorithm*, *45*, 41–51.

Chang, T.-S. (2008). Best routes selection in international intermodal networks. *Computers & operations research*, *35*(9), 2877–2891.

Cho, J. H., Kim, H. S., & Choi, H. R. (2012). An intermodal transport network planning algorithm using dynamic programming—a case study: from busan to rotterdam in intermodal freight routing. *Applied Intelligence*, *36*(3), 529–541.

Cho, J. H., Kim, H. S., Choi, H. R., Park, N. K., & Kang, M. H. (2007). An intermodal transport network planning algorithm using dynamic programming. In *New trends in applied artificial intelligence* (pp. 1012–1021). Springer.

Christofides, N. (1976). The vehicle routing problem. *Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle*, *10*(1), 55–70.

Clarke, G. u., & Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations research*, *12*(4), 568–581.

Dantzig, G. B., Orden, A., Wolfe, P., et al. (1955). The generalized simplex method for minimizing a linear form under linear inequality restraints. *Pacific Journal of Mathematics*, *5*(2), 183–195.

Desrochers, M., Lenstra, J. K., & Savelsbergh, M. W. (1990). A classification scheme for vehicle routing and scheduling problems. *European Journal of Operational Research*, *46*(3), 322–332.

Desrochers, M., & Verhoog, T. (1989). A matching based savings algorithm for the vehicle routing problem. *Cahiers du GERAD*.

Eksioglu, B., Vural, A. V., & Reisman, A. (2009). The vehicle routing problem: A taxonomic review. *Computers & Industrial Engineering*, *57*(4), 1472–1483.

European Commission. (2015). *The 5 targets for the EU in 2020.* Retrieved 2015-03-13, from http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/targets/

European Parliament. (2015). *REGULATION (EC) No 561/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 March 2006 on the harmonisation of certain social legislation relating to road transport and amending Council Regulations.* Retrieved 2015-06-03, from http://eur-lex.europa.eu/resource.html?uri=cellar:5cf5ebde-d494-40eb-86a7-2131294ccbd9.0005.02/DOC_1&format=PDF

Eurostat. (2015a). *Container transport performance.* Retrieved 2015-03-13, from http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Container_transport_performance_-_1_000_TEU-KM_2013.png

Eurostat. (2015b). *Modal split in the Netherlands.* Retrieved 2015-03-13, from http://ec.europa.eu/eurostat/web/products-datasets/-/tran_hv_frmod

Fisher, M. L., & Jaikumar, R. (1981). A generalized assignment heuristic for vehicle routing. *Networks*, *11*(2), 109–124.

Gendreau, M., Hertz, A., & Laporte, G. (1994). A tabu search heuristic for the vehicle routing problem. *Management science*, *40*(10), 1276–1290.

Gillett, B. E., & Miller, L. R. (1974). A heuristic algorithm for the vehicle-dispatch problem. *Operations research*, *22*(2), 340–349.

Goel, A., & Gruhn, V. (2008). A general vehicle routing problem. *European Journal of Operational Research*, *191*(3), 650 - 660. doi: http://dx.doi.org/10.1016/j.ejor.2006.12.065

Goetschalckx, M., & Taylor, W. (1987). A decision support system for dynamic truck dispatching. *Computers & Industrial Engineering*, *13*(1), 120–123.

Harris, I., Wang, Y., & Wang, H. (2015). Ict in multimodal transport and technological trends: Unleashing potential for the future. *International Journal of Production Economics*, *159*(0), 88 - 103. doi: http://dx.doi.org/10.1016/j.ijpe.2014.09.005

Johnson, D. S., Aragon, C. R., McGeoch, L. A., & Schevon, C. (1989). Optimization by simulated annealing: an experimental evaluation; part i, graph partitioning. *Operations research*, *37*(6), 865–892.

Kirkpatrick, S., Gelatt, C. D., Vecchi, M. P., et al. (1983). Optimization by simulated annealing. *science*, *220*(4598), 671–680.

Koc, C., & Karaoglan, I. (2011). A branch and cut algorithm for the vehicle routing problem with multiple use of vehicles. In *Proceedings of the 41st international conference on computers & industrial engineering. los angeles, usa.*

Kolisch, R., & Drexl, A. (1996). Adaptive search for solving hard project scheduling problems. *Naval Research Logistics (NRL)*, *43*(1), 23–40.

Laporte, G., & Nobert, Y. (1983). A branch and bound algorithm for the capacitated vehicle routing problem. *Operations-Research-Spektrum*, *5*(2), 77-85. Retrieved from `http://dx.doi.org/10.1007/BF01720015` doi: 10.1007/BF01720015

Lenstra, J. K., & Kan, A. (1981). Complexity of vehicle routing and scheduling problems. *Networks*, *11*(2), 221–227.

Li, J.-Q., Mirchandani, P. B., & Borenstein, D. (2007). The vehicle rescheduling problem: Model and algorithms. *Networks*, *50*(3), 211–229. Retrieved from `http://dx.doi.org/10.1002/net.20199` doi: 10.1002/net.20199

Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for or in intermodal freight transport research: A review. *European Journal of operational research*, *153*(2), 400–416.

Macharis, C., Caris, A., Jourquin, B., & Pekin, E. (2011). A decision support framework for intermodal transport policy. *European Transport Research Review*, *3*(4), 167–178.

NEO. (2015). *Vehicle routing problem.* Retrieved 2015-07-08, from `http://neo.lcc.uma.es/vrp/vehicle-routing-problem/`

Or, I. (1976). *Traveling salesman-type combinatorial problems and their relation to the logistics of regional blood banking*. Xerox University Microfilms.

Pirlot, M. (1996). General local search methods. *European journal of operational research*, *92*(3), 493–511.

Platform synchromodaliteit. (2015). *Definition Synchromodality.* Retrieved 2015-03-09, from `http://www.synchromodaliteit.nl/en/definition/`

Port of Rotterdam Authority. (2015). *Throughput port of rotterdam up 1%.* Retrieved 2015-02-10, from `http://www.portofrotterdam.com/en/News/pressreleases-news/Pages/throughput-port-rotterdam-1.aspx`

Ryan, D. M., Hjorring, C., & Glover, F. (1993). Extensions of the petal method for vehicle routeing. *Journal of the Operational Research Society*, 289–296.

Schutten, M. (2013). *Lecture sheets Discrete Optimization of Business Processes - University of Twente.*

Singh, P., & Van Sinderen, M. (2015). Interoperability challenges for context-aware logistic services - the case of synchromodal logistics. In (Vol. 1414). (cited By 0)

Singh, P. M. (2014). Developing a service oriented it platform for synchromodal transportation. In *On the move to meaningful internet systems: Otm 2014 workshops* (pp. 30–36).

Solomon, M. M. (1987). Algorithms for the vehicle routing and scheduling problems with time window constraints. *Operations research*, *35*(2), 254–265.

Speier, C., Valacich, J. S., & Vessey, I. (1999). The influence of task interruption on individual decision making: An information overload perspective. *Decision Sciences*, *30*(2), 337–360.

Steadieseifi, M., Dellaert, N., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research*, *233*(1), 1-15. (cited By 0) doi: 10.1016/j.ejor.2013.06.055

Taillard, É. (1993). Parallel iterative search methods for vehicle routing problems. *Networks*, *23*(8), 661–673.

van Breedam, A. (1996). *An analysis of the effect of local improvement operators in genetic algorithms and simulated annealing for the vehicle routing problem*. RUCA.

Yang, J., Jaillet, P., & Mahmassani, H. (2004). Real-time multivehicle truckload pickup and delivery problems. *Transportation Science*, *38*(2), 135–148.

Appendix A

Background information of CTT's terminals

This appendix contains background information of CTT's terminals. Figure A.1 shows the network of CTT, with CTT's own inland terminals in Rotterdam, Hengelo, Bad Bentheim, and Almelo. CTT is mainly active in the Twente region, but expands its activities to Poland and Malmö. Table A.1 summarizes information about CTT's terminals. This appendix ends with an overview of additional services offered by CTT.

Figure A.1: Terminals in connection.

Table A.1: CTT's terminals

Rotterdam	**Bad Bentheim**
• 5,5 hectares of land • Modalities: Barge / Truck / Rail • BRZO license • 150 meter quay • Storage for dangerous goods • Daily departures to various terminals in Rotterdam and the hinterland. • Open 06:00 – 23:00	• 7500 m2 of land • 600 meter sidings • Modalities: Rail / Truck • 3 times a week a train to various terminals in Rotterdam, v.v. • 3 times a week a train to Malmö, v.v. • International Railway Connection • Open 06:00 – 23:00
Hengelo	**Almelo**
• 12,5 hectares of land, of which 25.000 m2 warehouse • 400 meter quay and accessible for class V vessels: 110 meters to 11.40 meters, with a draft of 2.20 meters • Modalities: Barge / Truck • Daily departures to various terminals in Rotterdam, vice versa • AEO & Entrepot C • Open 06:00 – 23:00	• Expected to be operational halfway 2015 • 3,2 hectares of land • Modalities: Barge / Truck • 350 meter quay which is accessible to Class V Ships. • Daily departures to various terminals in Rotterdam, vice versa • Open 06:00 – 23:00

Additional services of CTT

- Gas measurement. Some goods in containers (for example, the glue of shoes), produce gasses which may be harmful for the final customer when they open the container after a long transport. A certified gas expert of Ruvoma checks if the containers are clean and safe.
- Customs documentation. Import and export containers need customs documentation before transportation. On request, CTT provides this documentation.
- Container rental and sales. 20, 40, and 45 foot containers are available for rent and sale.
- EDI (Electronic Data Interchange) connection. A link between ICT systems of CTT and its customers to exchange information and communicate easily.
- Warehouse. A hall of 25,000 m^2 allows customers to store the goods from containers on pallets temporarily. Space is available to build two more warehouses of this size.
- Container depot. Empty containers from shipping lines can be stored temporarily at the terminal.
- Authorized Economic Operator (AEO). CTT has a AEO-certification, which means that CTT is customs compliant, and therefore may transport and store customs goods.

Appendix B

CTT in numbers

This chapter provides confidential background information about CTT's bookings. The bookings of the last year are analyzed in this section.

- CONFIDENTIAL -

Appendix C

Flowcharts planning at CTT

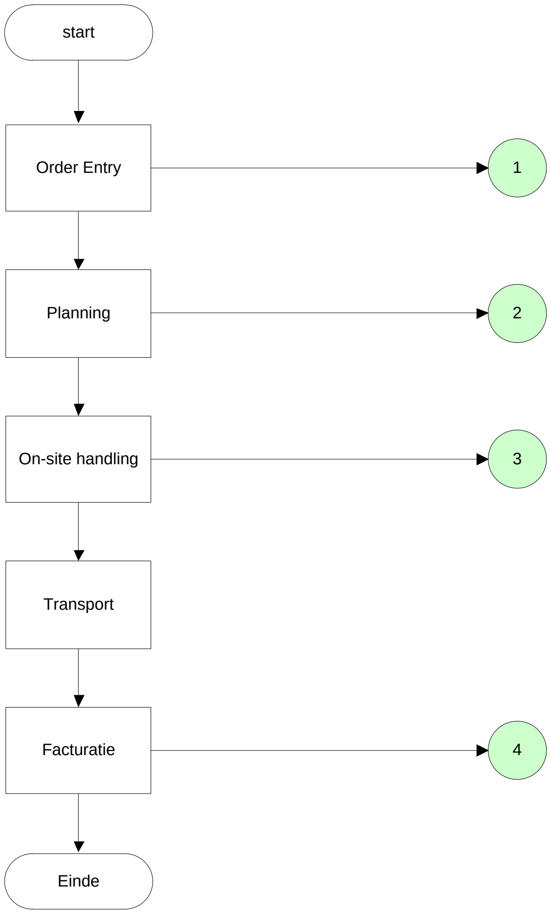
The upcoming pages give an overview (in Dutch) of the flowcharts used for the planning of trucks and barges at CTT. The flowchart for the planning of the train is missing, since this connection just started in September 2014.

Page 84 describes the general flow of a booking. The planning flowchart is given at page 85. The first stage, the barge planning, can be found on page 86. The second stage, the planning of trucking to sea terminals, are given at pages 87 and 88. The inland trucking planning is the last phase of planning and can be found at page 89.

CTT INTERMODAAL TRANSPORT

Moederflowchart CTT

Pagina	
Hoofdstuk	
Versie	
Datum	
Auteur	CPvision



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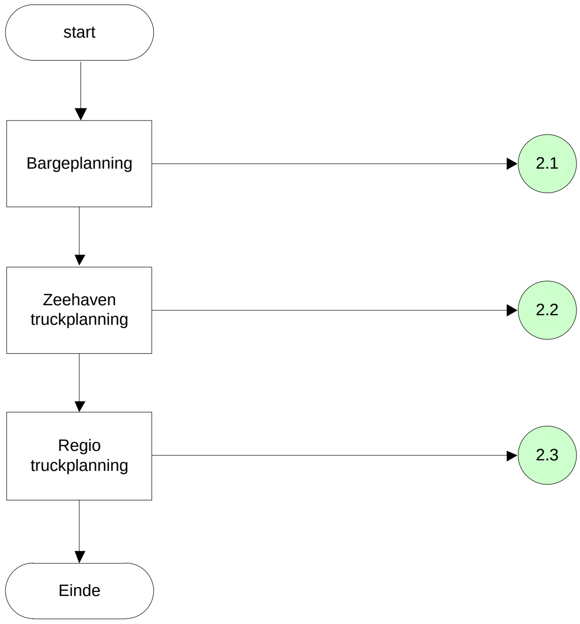
INTERMODAAL TRANSPORT	2. Planning	Pagina	
		Hoofdstuk	
		Versie	
		Datum	
		Auteur	CPvision



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CTT INTERMODAAL TRANSPORT

2.1 Bargeplanning

Pagina	
Hoofdstuk	
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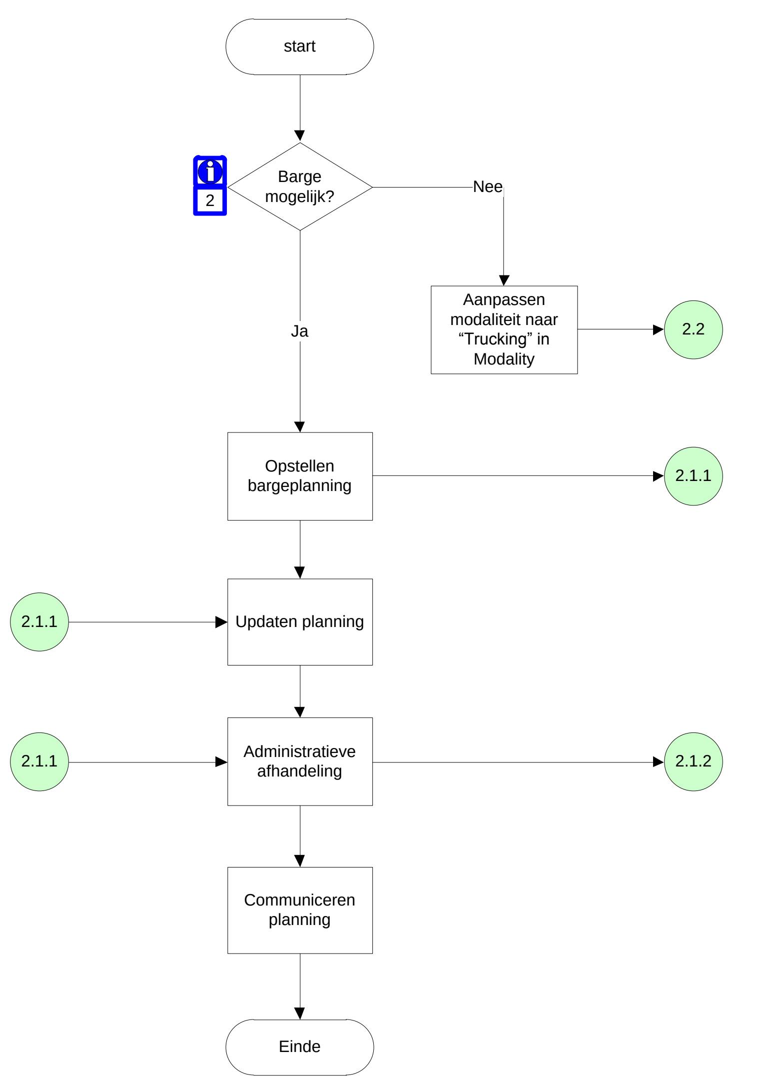
Auteur	CPvision



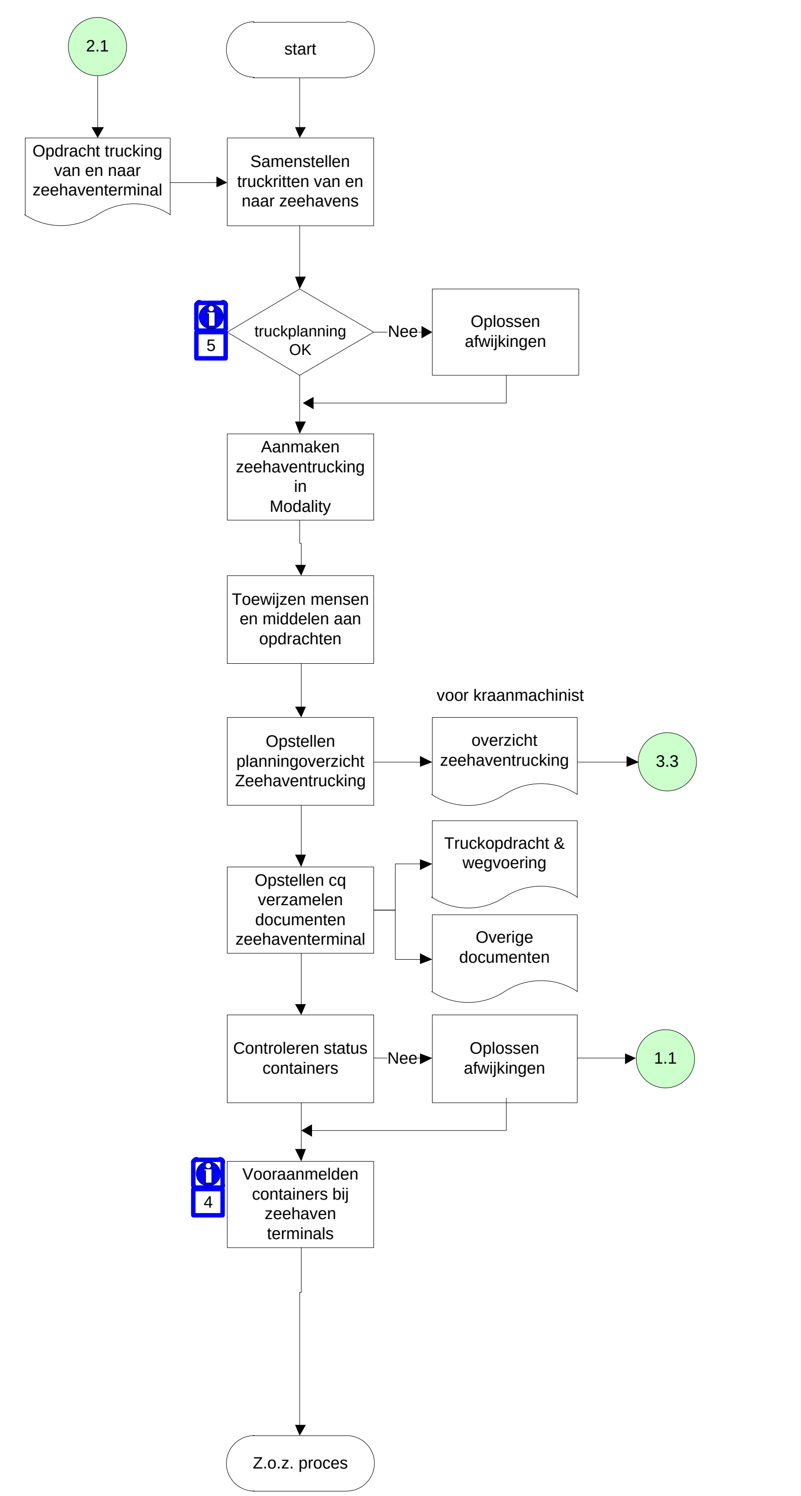
Previous step: 2

Functie	Omschrijving
Bargeplanner	Bepaald of trucking noodzakelijk vanwege spoed of vanwege capaciteitstekort barges
Truckplanner	Verandert de modaliteit in "Trucking" in Modality na overleg met de bargeplanner.
Bargeplanner	Stelt de bargeplanning op, zie proces 2.1.1
Bargeplanner	Updaten planning t.o.v. de reeds eerder gemaakte planning
Bargeplanner	Zorgt voor de administratieve afhandeling van de gemaakte planning, zie proces 2.1.2
Bargeplanner	Communiceert de planning met de schipper en zeehaven terminal. Eventueel al voor aankomst van de lichter (voor opstellen stuwplan)

Next Step: 3

Print Date		Document Name:	20081010-0.5_Flowchart CTT.vsd	Page	5

CTT INTERMODAAL TRANSPORT	**2.2 Zeehaven Truckplanning**	Pagina	
		Hoofdstuk	
		Versie	
		Datum	
		Auteur	CPvision



Previous step: 2

Functie	Omschrijving
Truckplanner	Stelt ritten van en naar zeehaventerminal samen op basis van de opdrachten in Modality
Truckplanner	Lost afwijkingen op indien deze zich voordoen in de truckplanning
Truckplanner	Maakt per truck het transport aan in Modality
Truckplanner	Wijst chauffeurs, chassis en trucks toe aan de samengestelde ritten
Truckplanner	Stelt een planningsoverzicht op met de samengestelde ritten
Truckplanner	Stelt truckopdrachten, CMR's, MRN's en overige documenten op per rit.
Truckplanner/ Customer Service	Controleert de status van de containers (of deze beschikbaar zijn)
Truckplanner	Meldt containers aan bij de zeehaventerminals

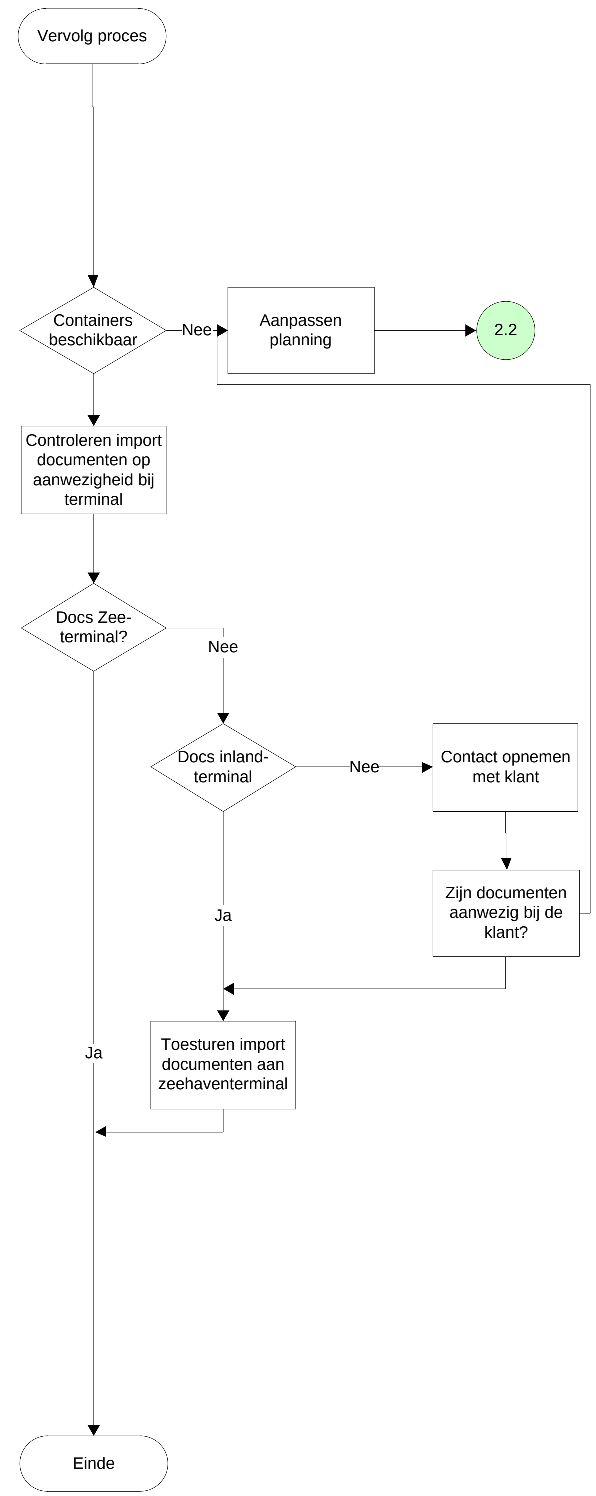
Next Step:

Print Date		Document Name:	20081010-0.5_Flowchart CTT.vsd	Page	9

CTT INTERMODAAL TRANSPORT

2.2 Zeehaven Truckplanning (2)

Pagina	
Hoofdstuk	
Versie	
Datum	
Auteur	CPvision



Previous step:

Functie	Omschrijving
Truckplanner	Past de zeehaven truckplanning aan indien een of meerdere containers niet beschikbaar zijn
Truckplanner	Controleren import documenten op aanwezigheid bij terminal (zonder documenten wordt container niet vrijgegeven)
Customer Service/ Truckplanner	Neemt contact op met de klant indien documenten niet aanwezig zijn
Customer Service/ Truckplanner	Zijn import documenten aanwezig bij de klant?
Truckplanner/ Klant	Afhankelijk van waar de importdocumenten aanwezig zijn worden de originele importdocumenten verstuurd naar de zeehaventerminal.

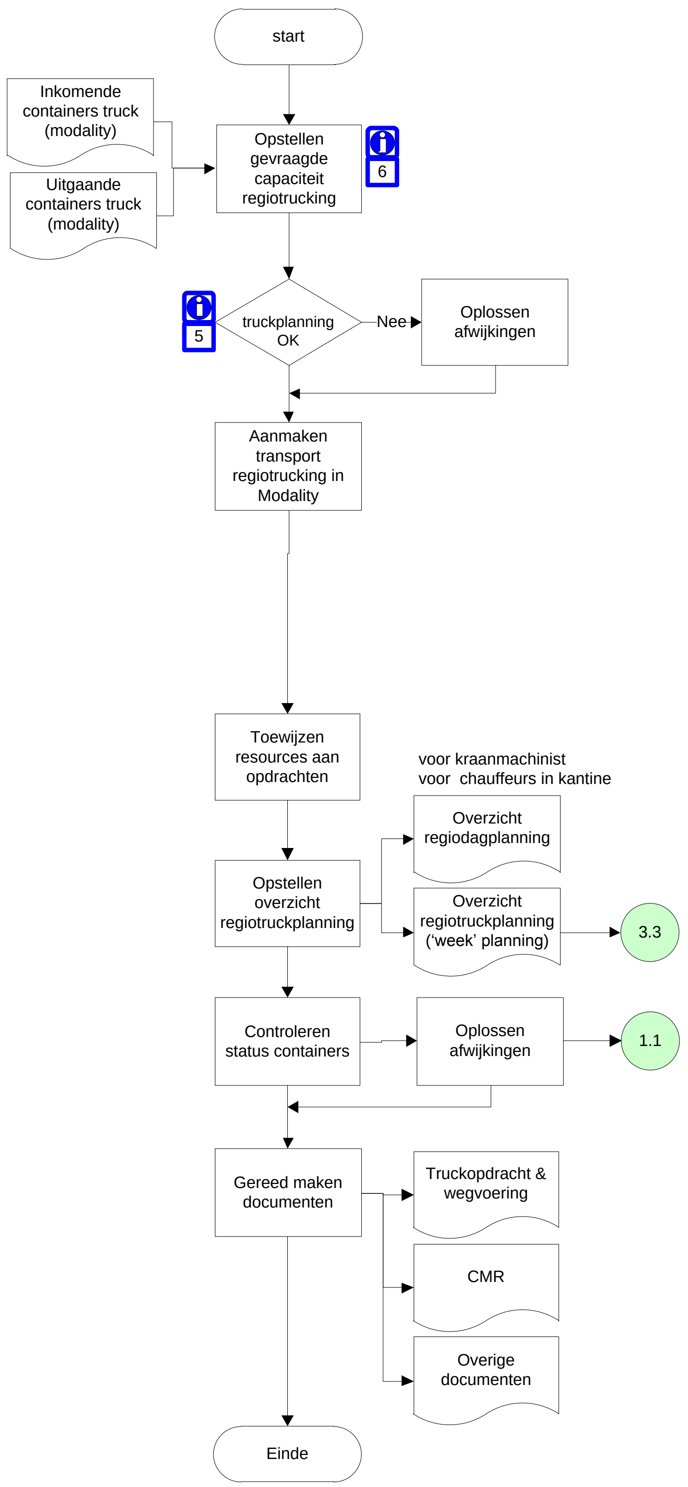
Next Step: 3

Print Date		Document Name:	20081010-0.5_Flowchart CTT.vsd	Page	10

INTERMODAAL TRANSPORT

2.3 Regio Truckplanning

Pagina	
Hoofdstuk	
Versie	
Datum	
Auteur	CPvision



Previous step: 2

Functie	Omschrijving
Truckplanner	Stelt de gevraagde capaciteit op (Containerlevering) en stemt de laad- en lostijden met klanten af
Truckplanner	Lost afwijkingen op indien deze zich voordoen in de truckplanning
Truckplanner	Maakt per truck het transport aan in Modality
Truckplanner	Wijst chauffeurs, chassis en trucks toe aan de gevraagde capaciteit
Truckplanner	Stelt een (dag) overzicht op met alle in- en af te leveren containers
Truckplanner/ Customer Service	Controleert de status van de containers (of deze beschikbaar zijn)
Truckplanner	Stelt CMR's op, verzamelt truckopdrachten MRN's, wegvoeringen en legt documenten gereed voor uit te leveren containers

Next Step: 3

Print Date		Document Name:	20081010-0.5_Flowchart CTT.vsd	Page	11

Appendix D

Classification method for vehicle routing problems

Section 3.1.3 mentioned two articles describing a method to classify VRPs. The list below describes the complete classification scheme of Desrochers et al. (1990).

The classification is divided in the subjects addresses, vehicles, problem characteristics, and objectives. The symbol $\vee$ stand for 'or'. The four subjects are subdivided in the following scheme:

1. Addresses := <number of depots><type of demand><address scheduling constraints><address selection constraints>

   (a) Number of depots := $1 \vee l$

1	[one depot]
l	[specified as part of the problem instance]

   (b) Type of demand $:=<\alpha_1><\alpha_2><\alpha_3>$

   $<\alpha_1>$:= $\circ \vee$ EDGE $\vee$ MIXED $\vee$ TASK

$\circ$	[node routing]
EDGE	[edge routing]
MIXED	[node and edge routing]
TASK	[task routing]

   $<\alpha_2>$:= $\circ \vee \pm$

$\circ$	[either all deliveries or all collections]
$\pm$	[mixed deliveries and collections]

   $<\alpha_3>$:= $\circ \vee \sim$

$\circ$	[deterministic demand]
$\sim$	[stochastic demand]

   (c) Address scheduling constraints

$\circ$	[no scheduling constraints]
fs_j	[fixed schedule]
tw_j	[single time windows]
mw_j	[multiple time windows]

   (d) Address selection constraints

$\circ$	[single plan; all addresses must be visited]

subset [single plan; a given subset of addresses must be visited]
choice [single plan; at least one address in each subset of a given partition must be visited]
period [a number of plans over a given time period is to be made]

2. Vehicles := <number of vehicles><capacity constraints><commodity constraints><vehicle scheduling constraints><route duration constraints>

   (a) Number of vehicles $:=< \beta_1 > \vee < \beta_2 >$

   $\beta_1 := \circ \vee =$
   - $\circ$ [at most β_2 vehicles can be used]
   - $=$ [all β_2 vehicles must be used]

   $\beta_2 := c \vee m$
   - $c (c \in \mathcal{N})$ [c vehicles]
   - m [specified as part of the problem instance]

   (b) Capacity constraints $:= \circ \vee cap \vee cap_i$
   - $\circ$ [no capacity constraints]
   - *cap* [vehicles with identical capacities]
   - cap_i [vehicles with different capacities]

   (c) Commodity constraints $:= \circ \vee sep \vee ded$
   - $\circ$ [no compartments]
   - *sep* [vehicles have interchangeable compartments]
   - *ded* [vehicles have dedicated compartments]

   (d) Vehicle scheduling constraints $:= \circ \vee tw \vee tw_i$
   - $\circ$ [no scheduling constraints]
   - *tw* [identical time windows for vehicles]
   - tw_i [different time windows for vehicles]

   (e) Route duration constraints $:= \circ \vee dur \vee dur_i$
   - $\circ$ [no route duration constraints]
   - *dur* [identical bounds on route duration]
   - dur_i [different bounds on route duration]

3. Problem characteristics := <type of network><type of strategy><address-address restrictions><address-vehicle restrictions><vehicle-vehicle restrictions>

   (a) Type of network $:=< \gamma_1 >< \gamma_2 >$

   $\gamma_1 := \circ \vee \Delta$
   - $\circ$ [general costs]
   - Δ [the costs satisfy the triangle inequality]

   $\gamma_2 := \circ \vee dir \vee mix$
   - $\circ$ [undirected network]
   - *dir* [directed network]
   - *mix* [mixed network]

   (b) Type of strategy $:=< \delta_1 >< \delta_2 >< \delta_3 >< \delta_4 >$

   $\delta_1 := \circ \vee / \vee \div$
   - $\circ$ [splitting of demand not allowed]
   - $/$ [a priori splitting of demand allowed]
   - $\div$ [a posterior splitting of demand allowed]

   $\delta_2 := \circ \vee$ *back* $\vee$ *full*
   - $\circ$ [no backhauling or full loads required]

back [backhauling, in case of node routing]
full [full loads, in case of task routing]

δ_3 := $\circ \vee \geq 1R/V$

$\circ$ [at most one route per vehicle]
$\geq 1R/V$ [more than one route per vehicle allowed]

δ_4 := $\circ \vee \geq 1D/R$

$\circ$ [a route starts and finishes at the same depot]
$\geq 1D/R$ [multi-depot routes allowed]

(c) Address - address restrictions $:=< \varepsilon_1 >< \varepsilon_2 >< \varepsilon_3 >$

ε_1 := $\circ \vee prec$

$\circ$ [no precedence constraints]
prec [precedence constraints]

ε_2 := $\circ \vee DA$

$\circ$ [no depot-address restrictions]
DA [depot-address restrictions]

ε_3 := $\circ \vee AA$

$\circ$ [no address-address restrictions]
AA [address-address restrictions]

(d) Address - vehicle restrictions $:= < \zeta_1 >< \zeta_2 >$

ζ_1 := $\circ \vee DV$

$\circ$ [no depot-vehicle restrictions]
DV [depot-vehicle restrictions]

ζ_2 := $\circ \vee AV$

$\circ$ [no address-vehicle restrictions]
AV [address-vehicle restrictions]

(e) Vehicle - vehicle restrictions $:= \circ \vee VV$

$\circ$ [no vehicle-vehicle restrictions]
VV [vehicle-vehicle restrictions]

4. Objective := <objective> ∨ <objective><objectives>

(a) Objective := ∘∨ <operator><function>

Operator := *sum* ∨ *max*

sum [minimize the sum of the cost function values]
max [minimize the maximum costs function value]

Function := $T_i \vee C_i \vee P_i$(<vehicle constraints>) $\vee C_j \vee P_j$(<address constraints>)

T_i [route duration]
C_i [vehicle costs]
P_i(<vehicle constraints>) [vehicle penalty]
C_j [address costs]
P_j(<address constraints>) [address penalty]

<vehicle constraints> := <vehicle constraint> ∨ <vehicle constraints><vehicle constraints>

<vehicle constraint> := $cap \vee cap_i \vee tw \vee tw_i \vee dur \vee dur_i$
<address constraint> $tw_j \vee mw_j$

Appendix E

List with solution methods for vehicle routing problems

This section shows a list with solution methods for VRPs in addition to the solution methods presented in Section 4.3. For more information about the solution methods, we refer to the related articles.

- Exact approaches
  - Branch and bound (e.g., Laporte and Nobert (1983))
  - Branch and cut (e.g., Koc and Karaoglan (2011))
- Classic heuristics
  - Constructive heuristics
    * Savings: Clark and Wright (Clarke & Wright, 1964)
    * Matching based (e.g., Altinkemer and Gavish (1991) and Desrochers and Verhoog (1989))
    * Nearest Neighbor (Solomon, 1987)
    * Adaptive search (Kolisch & Drexl, 1996)
    * Machine/Job shop scheduling (Beck, Prosser, & Selensky, 2003)
  - Improvement heuristics (van Breedam, 1996)
    * Or opt (Or, 1976)
    * r-opt (e.g., Alfa, Heragu, and Chen (1991)
- 2-Phase algorithms
  - Cluster-First, Route-Second
    * Fisher and Jaikumar (Fisher & Jaikumar, 1981)
    * The Petal Algorithm (Ryan, Hjorring, & Glover, 1993)
    * The Sweep Algorithm (e.g., Gillett and Miller (1974))
    * Taillard (Taillard, 1993)
  - Route-First, Cluster-Second (Beasley, 1983)
- Metaheuristics
  - Ant Colony Algorithms (Bell & McMullen, 2004)
  - Genetic Algorithms (Baker & Ayechew, 2003)

- Simulated Annealing (e.g., Kirkpatrick et al. (1983) and Cerny (1985))
- Tabu Search (e.g., Gendreau, Hertz, and Laporte (1994))

Appendix F

Mathematical model formulation

This section describes the mathematical model, which is related to the problem formulation in Section 4.2. The formulation is based on Goel and Gruhn (2008) and is used to program the solution method in Plant Simulation.

First, we describe the network of jobs and resources and the notation that is used. Second, we describe the indices, input parameters, decision variables, auxiliary variables, objective, and as last the constraints.

Let $\mathcal{C}$ be the set of containers to transport and $\mathcal{M}$ the set of all available trucks. For all containers c in $\mathcal{C}$, let $l_{c,1}, \ldots, l_{c,\lambda_c}$ be the locations belonging to container c. The node $i_{c,\mu}$ corresponds to $l_{c,\mu}$ for $1 \leq \mu \leq \lambda_c$.

The route of a truck m is denoted by $l_{m,1}, \ldots, l_{m,\lambda_m}$. For $1 \leq \nu \leq \lambda_m$, let $i_{m,\nu}$ denote a node corresponding to $l_{m,\nu}$.

The set $\mathcal{L}$ contains all locations of the trucks and the containers:

$$\mathcal{L} := \bigcup_{c \in \mathcal{C}} \left\{ i_{c,\mu} | 1 \leq \mu \leq \lambda_c \right\} \cup \bigcup_{m \in \mathcal{M}} \{ i_{m,\nu} | 1 \leq \nu \leq \lambda_m \} \tag{F.1}$$

The set $\mathcal{E}$ containers all edges between the nodes of the set $\mathcal{L}$:

$$\mathcal{E} := \mathcal{L} \times \mathcal{L} \setminus \{(i, i) | i \in \mathcal{L}\} \tag{F.2}$$

The graph $\mathcal{G} = (\mathcal{L}, \mathcal{E})$ represents the network with all locations and jobs. For this graph, we need to find routes for trucks, which at least fulfill the jobs, but can use additional moves (detours) to go from job to job. We assume a horizon of one day and all containers in the set $\mathcal{C}$ have to be transported on this day. Figure F.1 shows a small example of the network. A line without dots represents a job for the container. A dotted line is a move of a truck. The characters a to g represent different LD addresses. The text next to a normal line represents the job, indicated with the 'from' and 'to' location. The text to dotted lines represents the truck and the move of the truck.

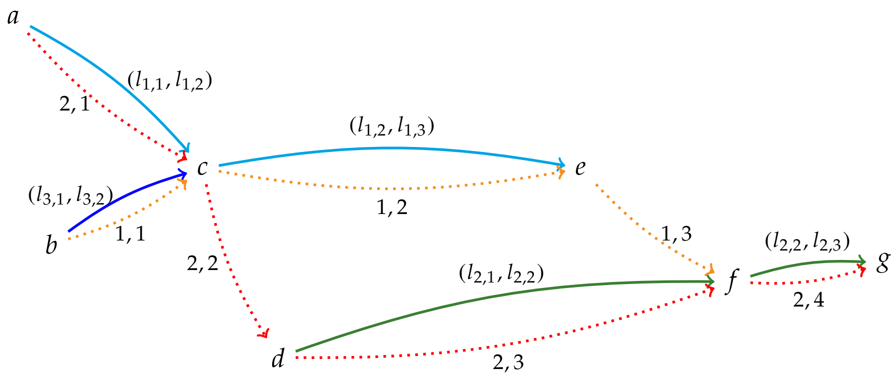


Figure F.1: Example graph

We see that there are three jobs in the network, the dark blue, light blue, and green lines. Furthermore, we see that that are two trucks that fulfill the jobs, which are truck 1 and 2. The first truck drives from b to c to e to f to g. The second truck drives from a to c to e to f. Move 3 from truck 1 (from e to g) and trip 2 from truck 2 (from c to d) are detours, because there is no job related to this move. This means that this move does not yield profit for the truck or transport company. One of the optimization goals for making a schedule could be to minimize the number of detours or the total time spend on detours. Instead of using two trucks, it may be possible to use only one truck, but this schedule is only feasible if drive and work restrictions of truck drivers are not violated. Also loading/discharge times and time window restrictions may not be violated.

Indices

These indices are used to specify the parameters in the model.

$\mathcal{C}$	Set of all containers.
$\mathcal{M}$	Set of all trucks.
$\mathcal{L} = \mathcal{L}_{\mathcal{T}} \cup \mathcal{L}_{\mathcal{C}}$	Set of all locations representing a terminal $\mathcal{L}_{\mathcal{T}}$ and customers $\mathcal{L}_{\mathcal{C}}$.
$(i, j) \in \mathcal{E}$	Set of all connections between the locations.
λ_c	Total number of locations for container c[1].
λ_m	Total number of locations for truck m.
c_μ	Location number μ of container c.
m_ν	Trip number ν of truck m, from $l_{m,\nu}$ to $l_{m,\nu+1}$.

Input parameters

Input data for the model are given below. The parameters are divided in the categories trucks, locations, and containers.

[1] Usually, a container c has a pickup address $l_{c,1}$, loading/discharge address $l_{c,2}$ and delivery address $l_{c,3}$.

Trucks

$\text{cap}_{m,v}$	Capacity of truck m, trip v, in TEU.
WorkHours_m	Allowed number of hours to work of truck m at one day.
EST_m	Earliest starting time for truck m.
LET_m	Latest end time for truck m.
C_m	Costs for using one modality one day.
C_w	Costs for waiting one hour at customer location.

Locations

$\text{dist}(i, j)$	Matrix with distances between locations i and j.
$\text{costs}(i, j)$	Matrix with costs between locations i and j
$\text{TT}(i, j)$	Matrix with travel time between locations i and j
$[E^i, L^i]$	Earliest and latest arrival time at address i.

Containers

size_c	Size of the container in TEU of container c.
$\text{PT}_{c,\mu}$	Earliest pickup time of container c at address $l_{c,\mu}$, for $\mu = 1, \ldots, \lambda_c - 1$.
$\text{DT}_{c,\mu}$	Latest delivery time of container c at address $l_{c,\mu}$, for $\mu = 2, \ldots, \lambda_c$.
$\text{S}_{c,\mu}$	Service time[2] for container c at address $l_{c,\mu}$.
dec_c	dec^c is equal to zero if decoupling is allowed and equal to one if decoupling is not allowed

Decision variables

The decisions that is central in the model is the allocation of a container on a trip of the truck.

Trucks

$x_{m,v}^{(l_{c,\mu}, l_{c,\mu+1})}$	If container c is transported by truck m, trip v from $l_{c,\mu}$ to $l_{c,\mu-1}$, for $\mu = 1, \ldots, \lambda_c + 1$.

Auxiliary variables

Auxiliary variables are used to simplify the upcoming constraints.

Trucks

$y_{m,v}^{(i,j)}$	If truck m, trip v travels from i to j.
y_{mn}	If truck m is used on day n.
dur_m	Total working hours for truck m.
$\text{arr}_{m,v}$	Arrival time of truck m, trip v.
$\text{dep}_{m,v}$	Departure time of truck m, trip v.
$z_{m,v}^{(i,j)}$	If $z_{m,v}^{(i,j)}$ is equal to 1, modality m, trip v, between i and j is driving without a container.

Locations

[2] Service time is loading/discharge time and waiting time.

$SS_{c,\mu}$	Start of service for container c at address $l_{c,\mu}$.

Containers

$\text{dep}_{c,\mu}$	Departure time for container c at location $l_{c,\mu}$.
$\text{arr}_{c,\mu}$	Arrival time of container c at address $l_{c,\mu}$.

Objective

Different objectives for the model can be formulated.

- minimize total costs (travel, vehicle and waiting costs)

$$\min\left(\sum_{m}\sum_{\nu=1}^{\lambda_m-1}\text{costs}\left(l_{m,\nu},l_{m,\nu+1}\right)\cdot y_{m,\nu}^{\left(l_{m,\nu},l_{m,\nu+1}\right)}+\sum_{m}y_m\cdot C_m+\sum_{m}\sum_{\nu=1}^{\lambda_m-1}\text{wait}_{m,\nu}\cdot C_w\right) \quad (F.3)$$

- minimize total distance

$$\min\left(\sum_{m}\sum_{\nu=1}^{\lambda_m-1}\text{dist}\left(l_{m,\nu},l_{m,\nu+1}\right)\cdot y_{m,\nu}^{\left(l_{m,\nu},l_{m,\nu+1}\right)}\right) \quad (F.4)$$

- minimize empty kilometres/detours

$$\min\left(\sum_{m}\sum_{\nu}\sum_{(i,j)}z_{m,\nu}^{(i,j)}\cdot\text{dist}(i,j)\right) \quad (F.5)$$

- minimize total makespan. Minimize the arrival of the last truck arriving.

$$\min\left\{\max_{m}\text{arr}_m\right\} \quad (F.6)$$

Constraints

The constraints that need to be taken into account are related to:

Trucks

- Capacity of truck (eq. F.7).
- Trucks can be used at one place at a time (eq. F.8).
- Departure, arrival and waiting times for trucks (eq. F.9 and F.10)r
- Containers and truck depart at same time (eq. F.11).
- Availability of truck (eq. F.12 to F.13).
- Working hours of driver of truck (eq. F.14 to F.15).
- Sequence of trucks (eq. F.16).
- Final destination truck (eq. F.17).
- Detours of truck (eq. F.18 and F.19).
- From and two location, flow constraints?

Containers

- A container can be transported with exactly one truck on a trip from address to address (eq. F.20).
- Container is suitable for truck (eq. F.21).
- Time constraints (pickup and delivery dates) (eq. F.22 to F.26).
- Waiting time containers (eq. F.27).
- Decoupling of containers (eq. F.28).

Locations

- Time windows at locations (eq. F.29).

The constraints are written out in the equations below.

Trucks

Capacity of truck
The number of containers on one truck is limited by the capacity $cap_{m,\nu}$ of the truck. The capacity of a truck can change for a trip when the chassis is changed (at the terminal).

$$\sum_{c} \sum_{\mu=1}^{\lambda_c - 1} \text{size}^c \cdot x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} \leq cap_{m,\nu} \qquad \forall m, \nu \tag{F.7}$$

Trucks can be used at one place at a time
A truck cannot perform different trips at the same time.

$$\sum_{(i,j)\in\mathcal{L}} y_{m,\nu}^{(i,j)} \leq 1 \qquad \forall m, \nu \tag{F.8}$$

Departure, arrival and waiting times for trucks
The arrival and departure times at a location are of interest to determine the waiting time of a truck. Additional costs are charged to the customers, if the waiting time is too long.

$$\text{dep}_{m,\nu} + \sum_{c} \sum_{\mu} TT(l_{c,\mu}, l_{c,\mu+1}) \cdot x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} = \text{arr}_{m,\nu} \qquad \forall m, \nu \tag{F.9}$$

The waiting time of a truck is denoted by the equation below. Trip ν is increased by one when arriving at a location, so the index for the departure time is $\nu + 1$, but this is the same location of the arrival.

$$\text{wait}_{m,\nu} = \text{dep}_{m,\nu+1} - \text{arr}_{m,\nu} \qquad \text{for } 1 \leq \nu \leq \lambda_m - 1 \tag{F.10}$$

Containers and truck depart at same time
The departure times for truck and container, $\text{dep}_{m,\nu}$ and $\text{dep}_{c,\mu}$, should be the same, if truck m,

trip ν, transports the corresponding container c_μ.

$$dep_{m,\nu} \cdot x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} = dep_{c,\mu} \cdot x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} \tag{F.11}$$

Working and rest hours of driver of truck

The truck is available between earliest starting time EST and latest end time LET.

$$EST_m \leq \text{dep}_{m,1} \qquad \forall m \tag{F.12}$$

$$\text{arr}_{m,\lambda_m} \leq LET_m \qquad \forall m \tag{F.13}$$

Regulations for the driving hours for truckers are limited by government (European Parliament, 2015). The main characteristic is to have a maximum of 9 working hours per day, with a rest after 4.5 hours of at least 45 minutes. It is assumed that drivers can take their rest at the addresses to load or discharge a container. Only a maximum of $Workhours_{mn}$ per day are taken into account. A truck driver is working when he or she is driving.

$$dur_m = \sum_{\mu=1}^{\lambda_c - 1} \sum_{\nu=1}^{\lambda_m} \left(TT\left(l_{c,\mu}, l_{c,\mu+1}\right) \cdot x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} \right) \qquad \forall m \tag{F.14}$$

$$dur_m \leq WorkHours_m \qquad \forall m \tag{F.15}$$

Sequence of trips

Trip $\nu + 1$ can never be performed if trip ν is not performed by truck m.

$$\sum_{i,j} y_{m,\nu}^{(i,j)} \geq \sum_{i,j} y_{m,\nu+1}^{(i,j)} \qquad \forall m, \nu \tag{F.16}$$

Last location of trucks

The trucks should end their day at one of the terminals from $\mathcal{L}_\mathcal{T}$.

$$\sum_{i} \sum_{j \in \mathcal{L}_\mathcal{T}} y_{m,\lambda_m}^{(i,j)} = 1 \qquad \forall m \tag{F.17}$$

Detours of truck

If a truck is driving without a container, the distance is registered as a detour.

$$y_{m,\nu}^{(l_{m,\nu}, l_{m,\nu+1})} - x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} \leq z_{m,\nu}^{(i,j)} \qquad \forall m, \nu = 1 \ldots \lambda_m - 1, c, \mu = 1 \ldots \lambda_c - 1, i, j \tag{F.18}$$

$$y_{m,\nu}^{(l_{m,\nu}, l_{m,\nu+1})} - x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})} \geq z_{m,\nu}^{(i,j)} \qquad \forall m, \nu = 1 \ldots \lambda_m - 1, c, \mu = 1 \ldots \lambda_c - 1, i, j \tag{F.19}$$

This can also be seen in Figure F.1. If there is both a truck move $y_{m,\nu}^{(l_{m,\nu}, l_{m,\nu+1})}$ and a container move $x_{m,\nu}^{(l_{c,\mu}, l_{c,\mu+1})}$, there is no detour $z_{m,\nu}^{(i,j)}$.

Containers

All containers should be delivered or picked up.
Each container has to be transported exactly once with exactly one truck m, on one trip ν.

$$\sum_m \sum_\nu x_{m,\nu}^{(l_{c,\mu},l_{c,\mu+1})} = 1 \qquad \forall c \text{ and } 1 \leq \mu \leq \lambda_c - 1 \tag{F.20}$$

Container is suitable for truck
If a truck is not available on a day, or for specific containers, the decision variable $x_{m,\nu}^{(l_{c,\mu},l_{c,\mu+1})}$ is set equal to zero beforehand. This reduces the solution space.

$$x_{m,\nu}^{(l_{c,\mu},l_{c,\mu+1})} = 0 \text{ if container } c \text{ cannot be executed by truck } m, \text{ trip } \nu, \text{ between } l_{c,\mu} \text{ and } l_{c,\mu+1}. \tag{F.21}$$

Time constraints
A route of a container consist of departure at location $l_{c,1}$, loading/discharge at location $l_{c,2}$ and finish at location $l_{c,3}$. This sequence is strict. Also the pickup dates, loading/discharge date and delivery dates should be taken into account. This results in equations F.22 to F.26.

$$\mathrm{PT}_{c,\mu} \leq \mathrm{SS}_{c,\mu} \qquad \forall c, \mu = 1,2 \tag{F.22}$$

$$\mathrm{SS}_{c,\mu} + \mathrm{S}_{c,\mu} \leq \mathrm{dep}_{c,\mu} \qquad \forall c, \mu = 1,2 \tag{F.23}$$

$$\mathrm{dep}_{c,\mu} + \mathrm{TT}(l_{c,\mu}, l_{c,\mu+1}) = \mathrm{arr}_{c_{\mu+1}} \qquad \forall c, \mu = 1,2 \tag{F.24}$$

$$\mathrm{arr}_{c,\mu} \leq \mathrm{SS}_{c,\mu} \qquad \forall c, \mu = 2,3 \tag{F.25}$$

$$\mathrm{arr}_{c,\mu} \leq \mathrm{DT}_{c,\mu} \qquad \forall c, \mu = 2,3 \tag{F.26}$$

Waiting time container
Additional costs can be involved when a truck has to wait at an address for too long, in general this is two hours. The waiting time can be calculated with the next formula:

$$\mathrm{wait}_{c,\mu} = \mathrm{dep}_{c,\mu} - \mathrm{arr}_{c,\mu} \tag{F.27}$$

Decoupling allowed
For some containers, decoupling of the containers at the customer is not allowed ($\mathrm{dec}^c = 1$). This means that the truck has to wait until the container is loaded or discharged, instead of taking another request for containers. Equation F.28 ensures that the truck both transports the container from $l_{c,1}$ to $l_{c,2}$ and from $l_{c,2}$ to $l_{c,3}$ in consecutive trips ν and $\nu + 1$.

$$x_{m,\nu}^{(l_{c,1},l_{c,2})} \cdot \mathrm{dec}^c \leq x_{m,\nu+1}^{(l_{c,2},l_{c,3})} \qquad \forall c, m, \nu \tag{F.28}$$

Locations

Time Windows
For the locations, both terminals and customer's addresses, time windows restrict the period in

which a container can be loaded or discharged.

$$E_{l_{c,\mu}} \leq SS_{c,\mu} \leq L_{l_{c,\mu}} \qquad \forall c, \mu \tag{F.29}$$

Appendix G

Steps for input data

The case that is tested in this thesis is gathered from data from Modality at CTT. Before the data can be used in the model, it first needs to be transformed. The template 'From Modality to Plant Simulation.xlsx' provides some functionalities, but some steps should be done manually. The enumeration below shows an stepwise approach to retrieve input data for the solution model from the database of Modality.

1. Choose day to schedule (DayToSchedule).
2. Select in Modality the period in which all transports for DayToSchedule took place (two weeks before and after DayToSchedule for example).
3. Export file to new Excel file.
4. Remove import and export documents columns, because of maximum number of columns of about 80. Save file as .CSV-file.
5. Import .CSV-file to phpMyAdmin.
6. Perform SQL in phpMyAdmin, with correct DayToSchedule and name of Tablefile

```
SELECT ‘Booking‘, ‘Container number‘, ‘Container type‘,‘Pickup date‘,
‘Import term. (oper.)‘, ‘Inland terminal‘,‘Truck OUT‘, ‘Gate OUT date‘,
‘Gate OUT time‘, ‘Loading/discharge address‘, ‘Load./dis. transport date‘,
‘Load./dis. transport time‘, ‘Truck IN‘,‘Gate IN date‘, ‘Gate IN time‘,
‘Inland terminal 2‘, ‘Export term. (oper.)‘, ‘Closing date‘, ‘Closing time‘
FROM ‘NAMEOFTABLEFILE‘ where ‘Gate OUT date‘=’DateToPlan’ OR
‘Gate IN date‘=’DateToPlan’ ORDER BY
‘NAMEOFTABLEFILE‘.‘Loading/discharge address‘ ASC
```

7. Copy the columns from above to the Excel-file.
8. Add the LA/DA/L/D manually if not recognized automatically. The A stands for decoupling ('afkoppelen' in Dutch), D for discharge, and L for loading of a container. Also check the purple columns once more for job numbers, addresses, and service times.

9. Adjust time columns to time format in Excel.
10. Rename ’type’ according to ’type2’ as follows:

Type2	Type
in	in
in/overnight	in
out	out
out/overnight	out
both	both

For ‘type2’=‘duplicate’, copy this rows and name the original rows as ‘out’ move and the copies rows to ‘in’ move. Also add manually ‘doublejob=true’ to out move, and ‘doublejob=false’ to in move. Besides, adjust the ‘Job’. For out moves, an ‘a’ must be added, for the in move, this must be a ‘b’. Do not forget to copy the formulas in the cells (indicated with purple) and unhide every column.

11. Check new locations for travel times and distances, and adjust column format in Plant Simulation (PS) if necessary. The Excel-file ‘Calculate Distances.xlsm’ can be used for this.
12. Adjust format of columns of Jobs, BestJobs and Initial jobs in PS.
13. Adjust ‘DateToPlan’ and ‘NoJobs’ in PS.
14. Run the experiment.

Modify existing input files to other scenarios/planning situations

There are three scenarios related to the basic situation. The input for these scenarios should be changed from the basic situation as follows.

No decoupling
When decoupling is not allowed, all jobs should be ‘L’ or ‘D’. This means that there are no jobs of ‘type2’=‘duplicate’ anymore, they become ‘both’. All FALSE doublejobs should be deleted. And the TRUE value should be deleted.

Always decoupling
To force decoupling, all jobs are of type ‘LA’ or ‘DA’. This results in ‘type2=duplicate’. Delete the old ‘FALSE’ jobs and copy the new duplicate jobs. Do not forget to update the purple rows, due to copying values only the row values.

No loading/discharge times
All the LD times should be deleted in the corresponding column.

Appendix H

Plant Simulation Model

This appendix gives an overview of the methods used in the Plant Simulation Model, as discussed in Section 5. Plant Simulation is actually a simulation software package, but also suitable as programming language. However, it is likely that other programming languages like C++ or Matlab are faster. An overview of the model can be found in Figure H.1.

The tables is divided in the following blocks:

- Input
- Output
- Experimental factors
- Methods
- Auxiliary

The next section describes the methods, table files, and variables for each of the above-mentioned bullets.

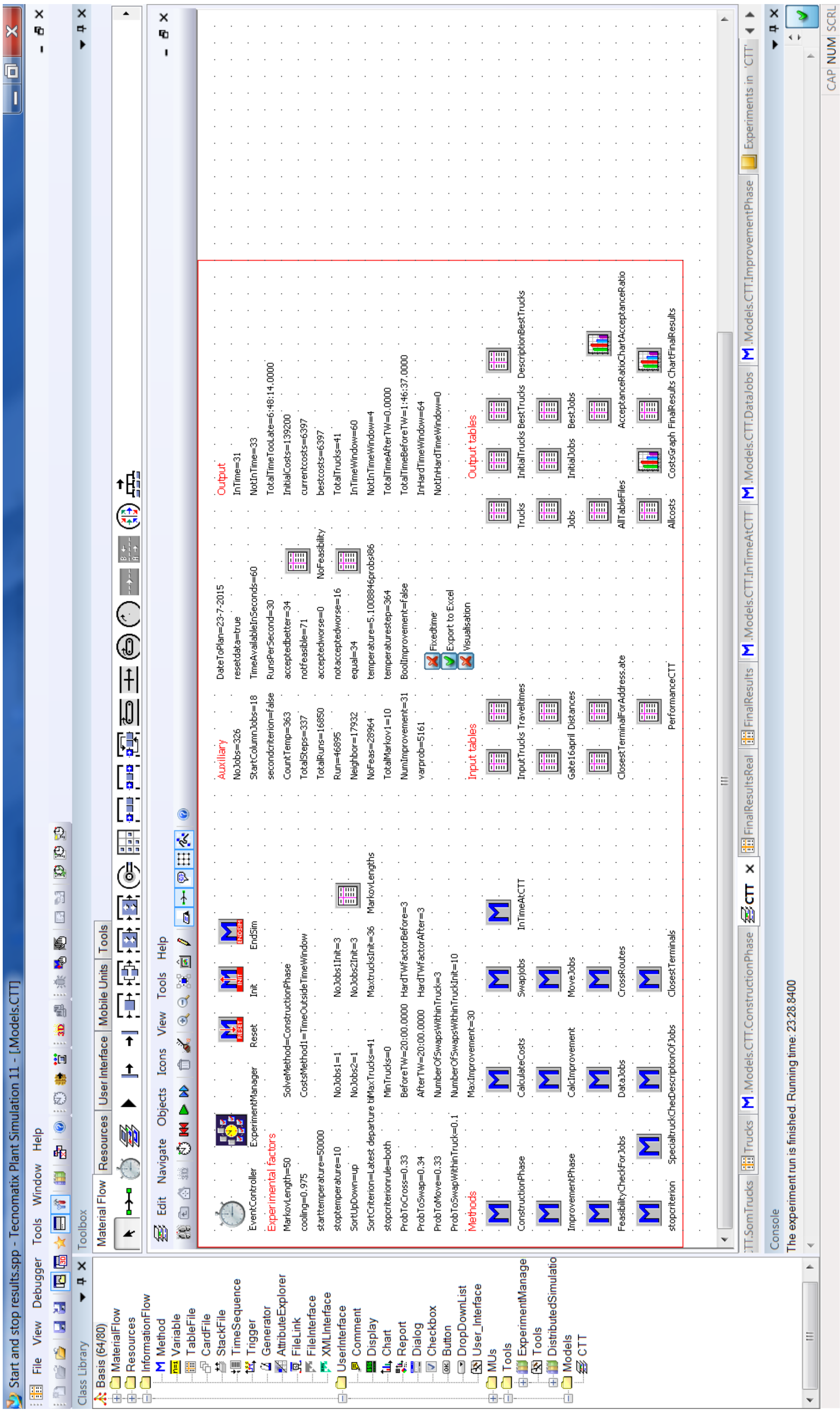


Figure H.1: Screenshot of Plant Simulation

Input

The input section contains all information needed to produce a schedule.

Name	Description
Input for trucks	This table containers information about the available trucks, which is: • Start location • Start time • Maximum working hours • Maximum driving hours • If the truck has a specific chassis (for example, a side-loader or tilt chassis) Optional: • End location • End time
Distances	Matrix with all distances between all locations
Travel times	Matrix with all travel times between all locations
Input data file (see Section G)	This table file contains all data of the containers with a gate out or gate in for the chosen day. The most important data is as follows: • Job ID • Booking number • Container number • Container type • Locations to visit (from, via, and to) • LD date and time • Truck OUT and Truck IN • Gate OUT date and time • Gate IN date and time • Type of trip (import, delivery, both, pick up, or export) • Decoupling at customer or not • Service time (for decoupling or loading/discharging) • Special type of truck needed (sideloader or tilt chassis) • Soft time window for container • Hard time window for container (opening hours) • Distance of job • Travel time of job

Output

Name	Description
Jobs per truck (from best solution found)	This table file shows the allocated jobs per truck, and also information about: • Total travel time • Total travel time and rest • Total number of detours • Total time of detours • Total distance • Total number of jobs • Total waiting time
Information per job (from best solution found)	The table-file contains the following information about each of the jobs: • Truck number • Trip number of truck • Arrival, departure, and end of service time • If relevant, if the container was in time at the LD address • Auxiliary information about feasibility of job
All costs of all feasible solutions	The table-file and graph give insight in all costs types.
Costs of best solution	The best solution value found during execution of the algorithms.

Experimental factors

Name	Description
Start temperature	The start temperature determines the probability of accepting a worse solution. This can be set by using 'Acceptance fraction'
Stop temperature	The stop temperature determines when the algorithm stops, when 'Allowed number of Markov Chains without change' is no stop criterion.
Cooling down factor	Determines how fast the temperature cools down.
Length of Markov Chain	The number of neighbor solution to look for at one temperature level.

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Name	Description
Acceptance fraction	The ratio of the average deterioration in the first chain divided by the number of worse solutions. This can be used to set the start temperature, such that this fraction of worse solutions is accepted.
Allowed number of Markov Chains without change	If there is no improvement for this number of temperature decreases, the algorithm stops.
Optimization goal	The objective to determine the optimal schedule.
Date to schedule	The day to schedule. This is used in the methods.
Number of jobs for improvement operator	This determines to move or swap 1, 2, or 3 jobs at once.
Sort criterion	The initial solution is based on this sort criterion, which can be for example randomly, or the latest departure time.
Stop criterion	Determines if the algorithm stops when the temperature is lower than the stop temperature and/or number of temperature levels without improvement.
Probability for choosing the improvement operators	There are three improvement operators. The probability of choosing one of these, is set with these probabilities.
Probability to swap within a truck	If the improvement operator is a 'Swap' move, these swaps are with this probability, swaps a number of jobs within the routes of the two trucks.
Start number of trucks	The initial solution aims to find a feasible schedule with this number of trucks. If this is not possible, additional trucks are used, but these can be removed again in the improvement phase.
Minimum number of trucks	The minimum number of trucks that should be used in the improvement phase. If this is zero, there is no minimum. This can be used to force that all 'Minimum number of trucks' are used.

Methods

Name	Description
Construction phase	This method constructs an initial feasible schedule, according to the flowchart in Figure 4.11.
Improvement phase	This method is the algorithm for simulated annealing. Figure 4.12 showed this method.
Calculate costs for neighbor solution	Dependent on 'Type of costs', the costs of the neighbor solution are calculated.

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Name	Description
Calculate performances for truck t	This method calculates the performances as described at 'Jobs per truck'. The input for this method is the truck number t, which is in most cases one of the trucks involved with the improvement operators.
Feasibility check for truck t	This method checks if the allocation of jobs on truck t is feasible. A route of a truck is feasible if work and driving restrictions are not violated and the delivery and service of container is finished before the container is picked up. Also hard time window restrictions are checked.
Swap jobs between two trucks	This method provides the swap of two sequences of jobs between two trucks. It checks if this solution is better, or accepts it with a certain probability.
Move jobs from one truck to another truck	This method provides the move of two jobs between two trucks. It checks if this solution is better, or accepts it with a certain probability.
Cross routes of two trucks	This method provides the crossing of two routes between two trucks. It checks if this solution is better, or accepts it with a certain probability.
Calculate performance of CTT	This method is able to assess the input data of CTT on the number of containers in time and the number of trucks of that day.
Closest terminal	This method is able to calculate the distance to the closest terminal for each of the locations.

Auxiliary

Name	Description
Acceptance ratio	The graph visualizes the data for the acceptance ratio, which is needed to set the experimental settings.
Infeasible solutions	The table-file supports to keep track of errors in the methods related to improvement operators.

Appendix I

Experimental settings

This appendix describes the technical details of the experiments, which function as experimental factors in Plant Simulation.

Table I.1 shows the general settings, which are the same for all experiments. Table I.2 show all experiments. Table I.3 show the technical settings for the experiments in Plant Simulation.

Table I.1: General settings for experiments

Description parameter	Value
Number of runs	1
Feasibility of neighbor solutions	Neighbors need to be feasible

Table I.2: Experiments

Exp.	Costs method	Probabilities improvement operators	Length sequence of jobs	Stop criterion	Soft time windows	Hard time window	Cooling factor	Start temperature	Stop temperature
1	Not in time	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
2	Time too late	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
3	Not in soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	100	0.01
4	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
5	Total trucks	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.99	10	0.1
6	Total travel time	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	100000	5000
7	Total waiting	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	100000	10
8	Total detours	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.95	1000	1
9	Total time detours	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	100
10	Time outside time window	P(cross)=1	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
11	Time outside time window	P(move)=1	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
12	Time outside time window	P(swap)=1	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
13	Time outside time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	1	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
14	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 20 min, LD time + 20 min]	[LD time - 20, LD time + 20 min]	0.975	50000	10

Continued on next page

Table I.2 – continued from previous page

Exp.	Costs method	Probabilities improvement operators	Length sequence of jobs	Stop criterion	Soft time windows	Hard time window	Cooling factor	Start temperature	Stop temperature
15	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 5 min, LD time + 5 min]	[LD time - 15 min, LD time + 15 min]	0.975	50000	10
16	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 5 min, LD time + 5 min]	[LD time - 5 min, LD time + 5 min]	0.975	50000	10
17	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 1 hour, LD time + 1 hour]	[LD time - 3 hour, LD time + 3 hour]	0.975	50000	10
18	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Both	[LD time - 1 hour, LD time + 1 hour]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
19	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Only stop temperature	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
20	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	Only number of improvements	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10
21	Time outside soft time window	P(cross)=0.33, P(move)=0.33, P(swap)=0.34	Or-opt	One of the above	[LD time - 20 min, LD time + 20 min]	[LD time - 1 hour, LD time + 1 hour]	0.975	50000	10

Table I.3: Technical input for Plant Simulation

Exp.	Markov length	coo-ling	start-tempe-rature	stop-tempe-rature	sort-criterior	CostsMethod1	No-Jobs1-Init	No-Jobs2-Init	Max-trucks-Init	Prob-To-Cross	Prob-To-Move	Prob-to-Swap	Prob-To-Swap-Within-Truck	Before-TW	After-TW	Hard-TW-factor-Before	Hard-TW-factor-After	stop-criterior rule	Max-Impro-vement
1	50	0.975	100000	100	Random	TimeTooLate	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
2	50	0.975	50000	100	Randon	NotInTime	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
3	50	0.975	100	0.01	Random	NotIn-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
4	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
5	50	0.99	10	0.1	Random	TotalTrucks	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
6	50	0.975	100000	5000	Randon	TotalTravelTime	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
7	50	0.975	100000	10	Random	TotalWaiting	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
8	50	0.95	1000	1	Randon	TotalDetours	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
9	50	0.975	50000	100	Random	TotalTime-Detours	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
10	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	1	0	0	0.1	20:00	20:00	3	3	both	30
11	50	0.975	50000	10	Random	TimeOutside-TimeWindow	3	3	36	0	1	0	0.1	20:00	20:00	3	3	both	30
12	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0	0	1	0.1	20:00	20:00	3	3	both	30
13	50	0.975	50000	10	Random	TimeOutside-TimeWindow	1	1	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	both	30
14	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	1	1	both	30
15	50	0.975	50000	10	Random	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	5:00	5:00	3	3	both	30
16	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	5:00	5:00	1	1	both	30
17	50	0.975	50000	10	Random	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	60:00	60:00	3	3	both	30
18	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	60:00	60:00	1	1	both	30
19	50	0.975	50000	10	Random	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	temp	30
20	50	0.975	50000	10	Randon	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	noimpr	30
21	50	0.975	50000	10	Random	TimeOutside-TimeWindow	3	3	36	0.33	0.33	0.34	0.1	20:00	20:00	3	3	one	30

Appendix J

Verification

This appendix shows the results for the other KPIs to verify the settings of the simulated annealing algorithm, see section 5.3.

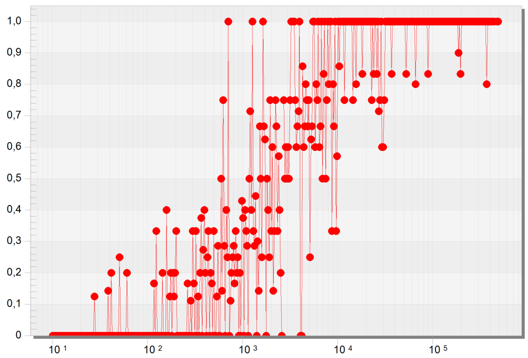

Figure J.1: Acceptance ratio 'Not in time'

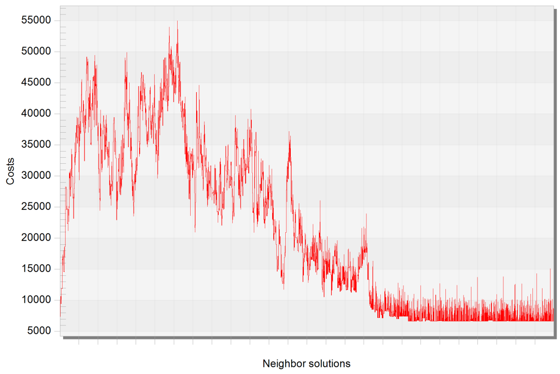

Figure J.2: Performance curve of 'Not in time'

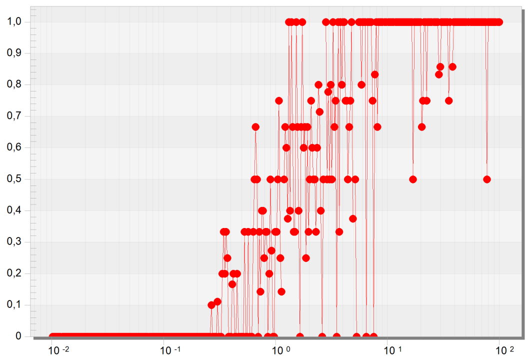

Figure J.3: Acceptance ratio 'Time too late'

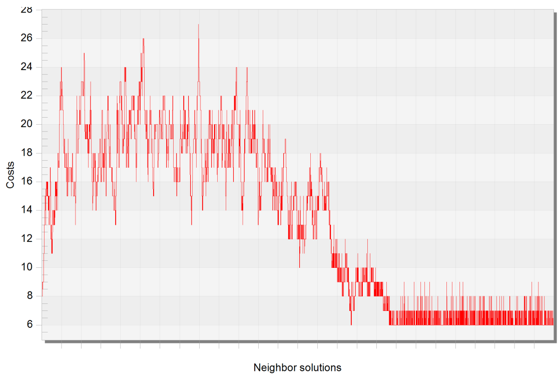

Figure J.4: Performance curve of 'Time too late'

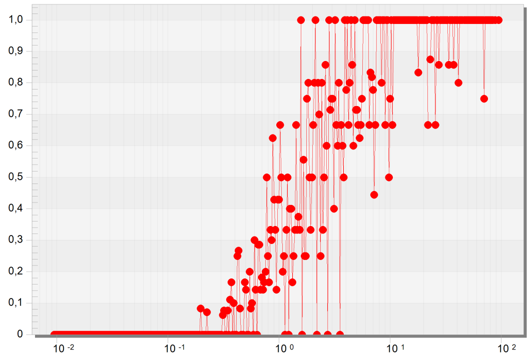

Figure J.5: Acceptance ratio 'Not in TW'

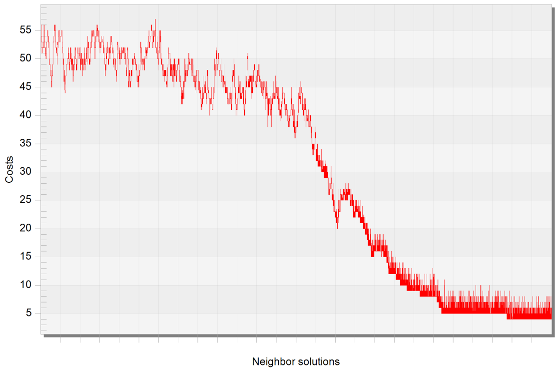

Figure J.6: Performance curve of 'Not in TW'

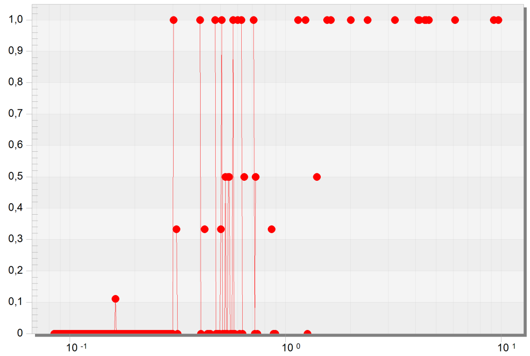

Figure J.7: Acceptance ratio 'Number of trucks'

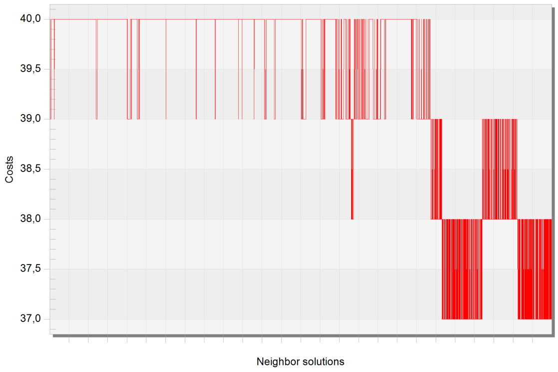

Figure J.8: Performance curve of 'Number of trucks'

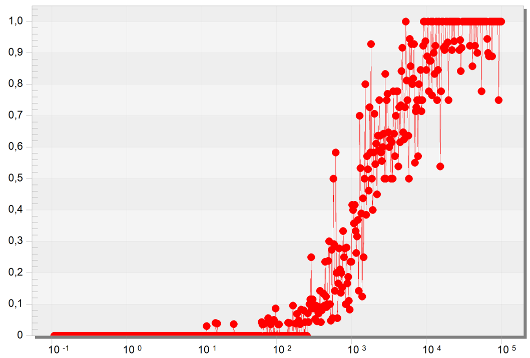

Figure J.9: Acceptance ratio 'Travel time'

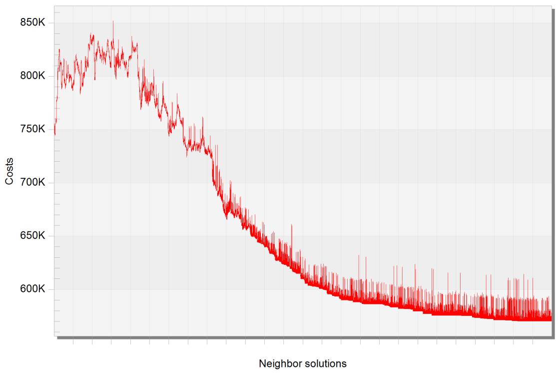

Figure J.10: Performance curve of 'Travel time'

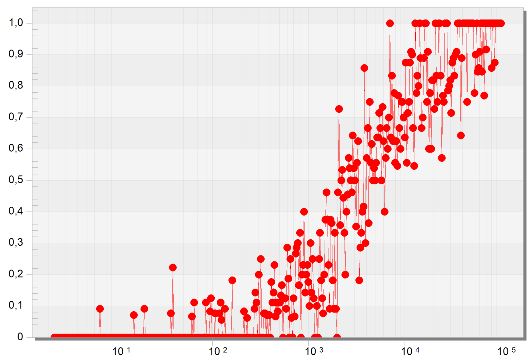

Figure J.11: Acceptance ratio 'Waiting time'

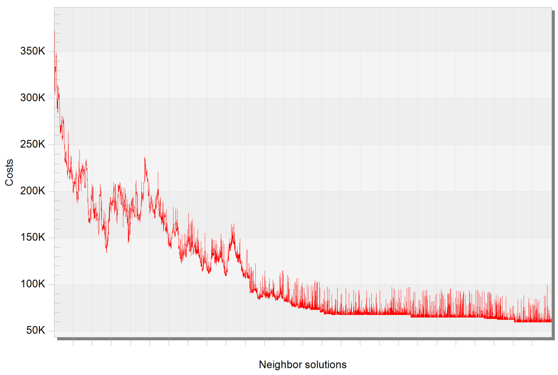

Figure J.12: Performance curve of 'Waiting time'

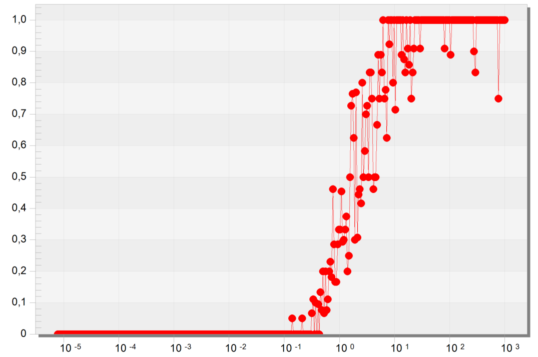

Figure J.13: Acceptance ratio 'Number of detours'

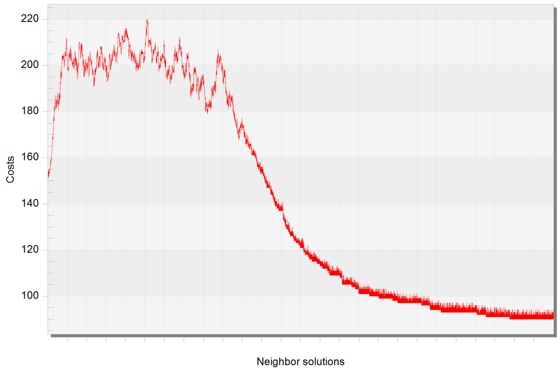

Figure J.14: Performance curve of 'Number of detours'

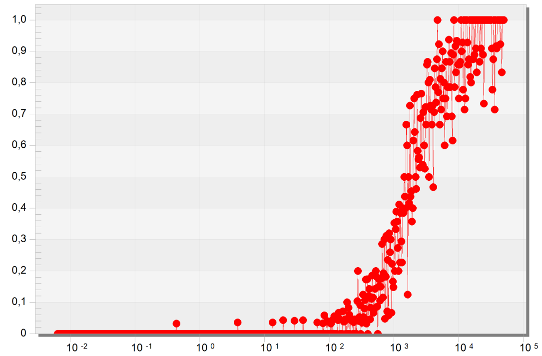

Figure J.15: Acceptance ratio 'Detour time'

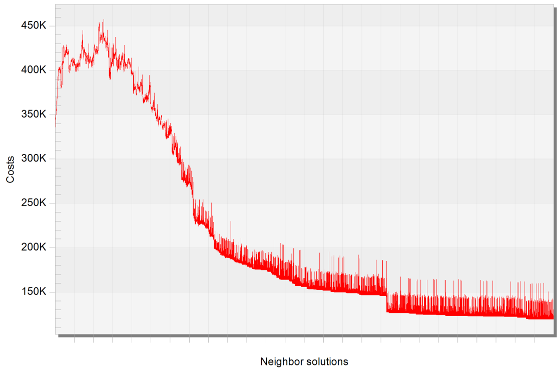

Figure J.16: Performance curve of 'Detour time'

Appendix K

Detailed results

This appendix contains the numerical results of all experiments, see Section 5.4.

	Not in time	Time too late	Not in TW	Time not in TW	Number of trucks	Travel time	Waiting time	Number of detours	Detour time
B1	6	0:01:51:18	58	1:01:06:58	42	8:11:27:16	4:11:29:13	144	3:22:49:27
B2	6	0:01:51:18	58	1:03:55:01	37	7:23:53:08	2:20:02:49	134	3:11:15:19
1	6	0:01:51:18	49	1:03:55:01	42	10:05:09:04	3:02:27:33	167	5:16:31:15
2	6	0:01:51:18	48	1:02:13:30	42	9:06:53:51	2:10:25:00	152	4:18:16:02
3	31	0:06:21:20	4	0:02:40:00	42	9:19:28:42	1:08:21:43	163	5:06:50:53
4	30	0:06:01:06	6	0:02:14:54	42	9:21:56:23	1:11:33:11	163	5:09:18:34
5	21	0:08:52:35	48	0:22:49:41	36	8:13:34:19	2:04:57:19	149	4:00:56:30
6	19	0:06:58:02	48	1:01:55:24	39	5:19:52:35	2:20:24:41	73	1:07:14:46
7	36	0:14:48:08	36	0:12:50:59	42	7:23:56:40	0:11:15:00	138	3:11:18:51
8	20	0:08:50:18	50	1:04:12:28	40	6:20:04:10	2:17:22:37	71	2:07:26:21
9	19	0:09:09:07	53	1:04:31:27	41	6:06:01:22	3:14:46:11	79	1:17:23:33
10	27	0:04:45:25	4	0:01:11:14	42	9:13:28:52	1:04:18:51	159	5:00:51:03
11	29	0:06:03:24	10	0:02:29:40	42	9:08:37:32	1:08:05:05	157	4:19:59:43
12	30	0:06:16:25	4	0:02:40:00	42	9:18:22:41	1:19:09:55	166	5:05:44:52
13	33	0:05:37:58	2	0:00:23:59	42	9:14:33:34	0:23:15:00	153	5:01:55:45
14	16	0:03:22:23	0	0:00:00:00	41	9:08:55:24	3:01:16:28	150	4:20:17:35
15	26	0:03:08:33	28	0:03:21:13	44	9:04:59:37	2:04:24:27	156	4:16:21:48
16	10	0:02:05:09	6	0:01:21:18	45	8:21:06:02	4:14:48:21	149	4:08:28:13
17	33	0:14:32:02	2	0:00:50:02	40	9:20:51:29	0:21:45:00	157	5:08:13:40
18	19	0:07:42:41	0	0:00:00:00	42	9:14:33:19	2:12:09:23	165	5:01:55:30
19	33	0:06:10:45	4	0:01:20:54	41	9:10:09:45	1:04:03:08	159	4:21:31:56
20	29	0:05:15:22	2	0:01:20:00	42	9:01:54:30	1:06:18:49	154	4:13:16:41
21	35	0:06:39:16	2	0:00:00:50	42	9:21:18:03	0:22:30:00	167	5:08:40:14

Figure K.1: Results no decoupling scenario

	Not in time	Time too late	Not in TW	Time not in TW	Number of trucks	Travel time	Waiting time	Number of detours	Detour time
B1	6	0:01:51:18	56	1:00:13:37	40	8:10:09:51	4:15:19:09	136	3:21:32:02
B2	6	0:01:51:18	58	1:02:46:19	36	8:15:47:23	3:00:35:03	139	4:03:09:34
1	6	0:01:51:18	45	1:00:13:37	39	10:08:33:49	2:15:26:07	299	5:19:56:00
2	6	0:01:51:18	50	1:05:27:44	40	10:04:47:24	2:22:37:20	300	5:16:09:35
3	25	0:05:04:22	7	0:04:40:00	40	10:23:53:40	1:19:51:48	294	6:11:15:51
4	31	0:06:05:27	6	0:02:19:55	40	10:19:38:14	1:02:47:16	296	6:07:00:25
5	18	0:08:25:44	50	1:01:39:58	38	10:14:25:08	2:12:53:36	294	6:01:47:19
6	19	0:07:18:31	44	1:00:17:22	40	5:19:37:14	3:06:58:33	98	1:06:59:25
7	28	0:12:28:48	37	0:12:31:36	40	9:16:09:50	0:18:00:00	279	5:03:32:01
8	13	0:04:35:16	46	1:02:46:19	39	7:08:28:30	3:16:30:08	108	2:19:50:41
9	20	0:07:37:48	47	1:02:18:21	39	5:17:38:10	3:15:55:04	95	1:05:00:21
10	25	0:05:23:10	7	0:03:11:40	40	11:03:09:08	1:08:00:25	283	6:14:31:19
11	24	0:05:50:44	12	0:05:18:48	39	10:02:33:27	1:14:40:46	285	5:13:55:38
12	23	0:04:47:30	11	0:05:11:27	40	9:22:03:03	2:02:58:15	296	5:09:25:14
13	38	0:06:48:49	8	0:01:42:13	40	10:20:01:09	1:07:21:14	287	6:07:23:20
14	9	0:02:02:13	0	0:00:00:00	42	10:02:15:59	3:15:46:53	297	5:13:38:10
15	25	0:02:54:36	34	0:05:17:22	44	10:14:40:26	3:04:52:14	290	6:02:02:37
16	7	0:01:54:40	6	0:01:21:18	43	9:13:46:22	4:13:52:24	268	5:01:08:33
17	30	0:13:03:11	3	0:02:13:37	41	11:07:50:02	1:05:13:59	284	6:19:12:13
18	22	0:11:09:19	0	0:00:00:00	40	10:09:40:07	2:21:02:30	283	5:21:02:18
19	36	0:06:54:34	6	0:02:29:20	39	10:19:30:43	1:07:47:04	306	6:06:52:54
20	29	0:06:20:12	6	0:02:53:29	40	10:07:58:16	1:12:16:35	288	5:19:20:27
21	31	0:06:42:07	4	0:01:30:57	40	10:20:25:11	1:06:18:57	289	6:07:47:22

Figure K.2: Results all decoupling scenario

	Not in time	Time too late	Not in TW	Time not in TW	Number of trucks	Travel time	Waiting time	Number of detours	Detour time
B1	0	0	0	0	37	9:02:18:06	0:21:45:00	197	4:13:40:17
B2	0	0	0	0	38	10:02:58:17	0:23:15:00	145	5:14:20:28
1	0	0	0	0	37	9:14:25:28	0:21:45:00	205	5:01:47:39
2	0	0	0	0	37	9:02:14:18	0:21:45:00	204	4:13:36:29
3	0	0	0	0	37	9:07:08:05	0:22:30:00	200	4:18:30:16
4	0	0	0	0	37	9:01:54:32	0:21:45:00	214	4:13:16:43
5	0	0	0	0	36	9:01:30:27	0:21:45:00	188	4:12:52:38
6	0	0	0	0	36	6:07:49:37	0:13:30:00	97	1:19:11:48
7	0	0	0	0	37	8:13:05:13	0:14:15:00	189	4:00:27:24
8	0	0	0	0	37	7:19:07:14	0:18:45:00	87	3:06:29:25
9	0	0	0	0	37	5:22:10:22	0:12:00:00	82	1:09:32:33
10	0	0	0	0	37	9:14:02:48	0:21:45:00	200	5:01:24:59
11	0	0	0	0	36	9:06:05:44	0:22:30:00	206	4:17:27:55
12	0	0	0	0	37	8:15:45:05	0:21:45:00	194	4:03:07:16
13	0	0	0	0	37	9:12:21:16	0:21:45:00	212	4:23:43:27
14	0	0	0	0	37	9:02:18:06	0:21:45:00	197	4:13:40:17
15	0	0	0	0	37	9:12:21:16	0:21:45:00	212	4:23:43:27
16	0	0	0	0	37	9:02:18:06	0:21:45:00	197	4:13:40:17
17	0	0	0	0	37	9:12:21:16	0:21:45:00	212	4:23:43:27
18	0	0	0	0	37	9:02:18:06	0:21:45:00	197	4:13:40:17
19	0	0	0	0	37	9:11:22:38	0:21:45:00	206	4:22:44:49
20	0	0	0	0	37	9:04:55:08	0:22:30:00	207	4:16:17:19
21	0	0	0	0	37	9:03:57:44	0:22:30:00	198	4:15:19:55

Figure K.3: Results no loading/discharge scenario

Appendix L

Performance of container transport

This appendix describes the steps to assess the performance for timeliness. The data is gathered from Modality and requires transport information of containers.

1. Export all container from Modality to Excel with a gate out move or gate in move at this day.

```
SELECT ‘Booking‘,‘Client‘,‘Booking type‘,‘Container number‘,
‘Container type‘,‘Inland terminal‘,‘Gate OUT date‘,‘Gate OUT time‘,
‘Truck OUT‘,‘Trucking company‘,‘Loading/discharge address‘,
‘Load./dis. transport date‘,‘Load./dis. transport time‘,
‘Loading/discharge reference‘,‘Gate IN date‘,‘Gate IN time‘,‘Truck IN‘,
‘Trucking company_1‘,‘Inland terminal 2‘,‘Internal remarks‘
FROM ‘NameOfFile‘
WHERE ‘Gate IN date‘=’DateToCheck’ OR ‘Gate OUT date‘=’DateToCheck’
```

2. Determine type of move (out, in, or both). If type is equal to both, duplicate this entry and assign ’Gate OUT’ and ’Gate IN’ to one of both. In the same way, assign ’Gate OUT’ to the out move and ’Gate IN’ to the in move.

3. Put columns in the next format of columns:
   - Job: Add unique job ID manually.
   - From: In case of gate OUT this is the Inland terminal, else this is the loading/discharge address.
   - Time: Gate OUT or gate IN time.
   - Truck: Truck ID of the date .
   - Job of truck: Job number of the truck, sorted ascending on ’Time’ .
   - Truck: License of truck.
   - To: Destination of the container movement.
   - What: If it is a gate OUT, gate IN, or both movement on this date.
   - Gate: If this part of the container movement is a Gate OUT of Gate IN movement.

- Distance: Distance between 'From' and 'To'.
- Speed: Assumed to be as in Table 5.1
- Travel time: Based on distance and average speed
- Arrival time: Estimated arrival time at 'To', based on 'Time' + 'Travel time'

4. Run macro's in MeasurePerformance.xlsm, sheet Results. It is possible to select a part of all trucks to get a more clear visualisation of the timeline.
    - Make timeline
    - Calc. waiting
    - Performances
5. Save results: timeline and table with performances per truck.