Inter-Terminal Transport with uncertain connections

Bachelor thesis

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This thesis is about controlling the transport of ITT containers. The way of transporting ITT containers that is analyzed in this thesis is the asset-light solution. The asset-light solution assumes that residual capacity of visiting trucks can be used to transport some of these ITT containers. The usage of the residual capacity of visiting trucks results in uncertain connections, because it is not always sure when and where visiting trucks have residual capacity. In addition to these visiting trucks, fixed trucks are needed to ensure that all containers are delivered on time. In this thesis we have looked at the transport of ITT containers for the Maasvlakte 2, a part of the Port of Rotterdam. A simulation model is used to determine the number of fixed trucks that is needed. The simulation is run without some fixed trips and with the fixed trips. In this way, the fixed trips represent the uncertain connections. The results of these simulations are compared for several variants of fixed trips. We concluded for the problem of the Maasvlakte that when using not too much different uncertain connections, the amount of extra trucks needed is almost equal for both cases (with and without the uncertain connections).

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1. Introduction

After years of planning, discussions and protests on 1 September 2008 the construction of Maasvlakte 2, the extension of the port of Rotterdam, started. By this extension a new transport system for inter-terminal transport in the port of Rotterdam has to be developed. Earlier studies Duinkerken et al. (1996), Ottjes et al. (1996) and Kurstjens et al. (1996) already showed transport systems for inter-terminal transport for the former non-expanded Maasvlakte 1.

Inter-terminal transport (ITT) is the transport of containers between terminals in a port. It is expected that, with the growth of terminals in the future the inter-terminal transport becomes more and more important (Vis & de Koster, 2003). This transport is important, because of the fact that not all terminals have good connections with all possible means of transport, like via inland waterways (barge), rail (train) or road (truck). There is, especially in the bigger ports, not enough space in order to ensure that all terminals have good connections with all possible means of transport. A terminal with a bad connection with a railroad can transport the containers, which should be transported to the hinterland via train, to a terminal with a good connection with a railroad. So, with inter-terminal transport terminals can help each other with the transport of containers.

The most important tasks of the ITT are: the punctual (neither early nor late) collection of containers from their point of origin and the punctual delivery of containers at the point of destination (Ottjes et al., 1996). For the inter-terminal transport several transport systems can be used. A fixed amount of trucks, which transports only containers between the terminals can be used, or a barge can be used that visits different terminals one after the other and transports the containers between these terminals.

Another way of transporting containers between terminals is to use residual capacity of visiting trucks, barges and trains, which is called the asset-light solution (Dekker et al., 2012). For example, if a truck (with a capacity of two containers) has to bring one container from terminal A to the hinterland and this truck comes along terminal B, he can transport one ITT-container from terminal A to terminal B. The usage of residual capacity of visiting vehicles brings with it uncertainties, because there is no information (or shortly beforehand) about how much residual capacity is available on a certain time at a certain terminal. This transport system for ITT is viewed in this thesis.

The main goal of this thesis is *to evaluate the effect of uncertain connections on the number of trucks needed to ensure that all ITT-containers arrive on time.* There are two ways to do this: via simulation, which Duinkerken et al. (1996) and Ottjes et al. (1996) did, or analytical, which Tierney et al. (2012) did. The model of Tierney et al. (2012) did not use the uncertain connections. Some benefits of a simulation are that a simulation is flexible and easy to understand. On the other hand simulations need (much) more time to have good results and are not always totally reliable. The advantages and disadvantages of an analytical model are the opposites of the advantages and disadvantages of a simulation. An analytical model is not flexible and sometimes very hard to understand, while on the other hand it takes less time than running a simulation and the results from an analytical model are more reliable than the results of a simulation.

In this paper is chosen for a simulation model, because it is easier to understand and easier to implement than using a model like Tierney et al. (2012) did and we expect that in this case a simulation will give reasonable good (not optimal) solutions. A discrete-time simulation with time steps of one minute is used to simulate the inter-terminal transport. Some decision rules are made in order to ensure that the transport of ITT-containers goes well. One of the decision rules is about the order of the loading or unloading of containers and another decision rule is about the choice on which vehicle a certain container is loaded. The other two are about generating empty trips and about the decision when a vehicle should leave a terminal. The idea of the simulation is to find, in addition to some barges and/or some fixed trips, the number of additional trucks that are needed to ensure that all containers arrive on time at their destination.

This paper is organized as follows. First the problem is described and the data is introduced in section 2. How the data is generated and a check if this is done correctly can also be found in section 2. Then the planning and control of transports is explained in section 3, followed by explaining the simulation model in section 4. In that section the decision rules are explained and a verification and validation of the model is done. Section 5 shows the results of the simulation for the problem of the Maasvlakte and finally, in section 6 a conclusion is given.

2. Problem description and data

As explained in the introduction a new transport system for ITT in the port of Rotterdam has to be created and this thesis shows the asset-light solution and how to plan transports with the uncertain connections. The idea is to simulate the problem of the Maasvlakte and compare the results with a simulation of the Maasvlakte with some uncertain connections, which are available a certain period of time. Which uncertain connections are used and the results of these simulations can be found in section 5. Figure 1 shows a map of the Maasvlakte with the number of ITT containers that should be transported in peak hours.

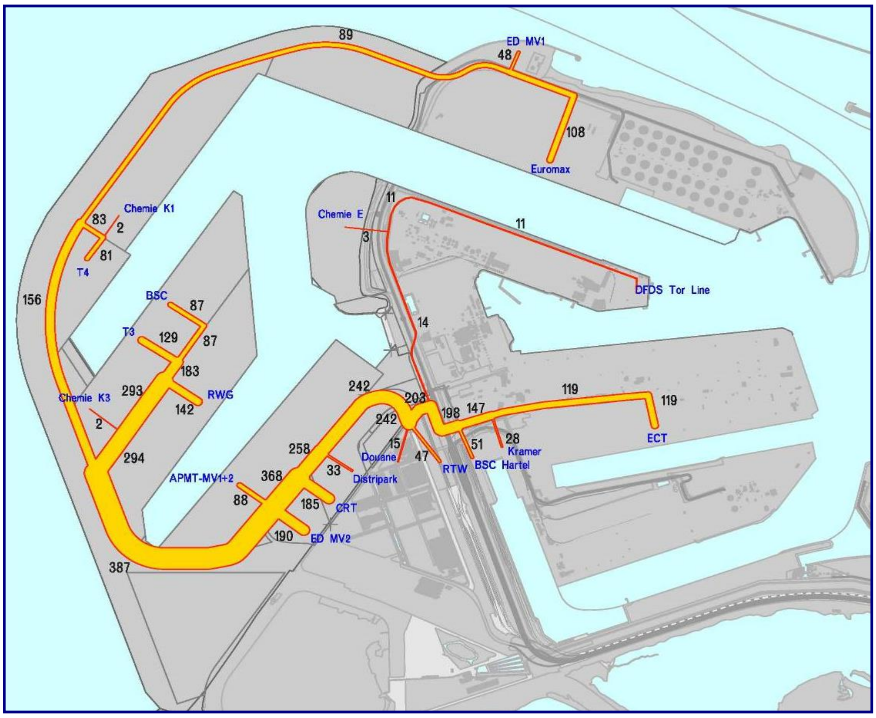

Figure 1: Number of containers at the ITT System of the Maasvlakte in peak hour (both directions) [1]

The data of the problem of the Maasvlakte consists the following:

[1] Source: Dekker et al. (2012)

- A matrix with the yearly amount of ITT-containers that should be transported between each pair of terminals
- A matrix with the road distances between all 19 terminals
- A matrix with all water distances between all 9 terminals that are attainable for barges
- A list with the names of the terminals that also shows which road terminal number belongs to which water terminal number

2.1 Generated data

For the simulation we need data about every single container. Of every single container we want to know the origin, destination, release time and deadline. The data mentioned in the previous section should be used to create the data for every single container, especially the matrix with the yearly amount of ITT-containers that should be transported between each pair of terminals. The matrix is first converted from yearly amounts to daily amounts. These daily amounts are used to generate the data we wanted.

For every hour a triangular distribution is used to determine how much containers release in that hour. The mean of the triangular distribution is the daily amount divided by 24, because a day has 24 hours. The maximum is chosen as two times the mean and the minimum is zero, so that at maximum twice as much as the mean containers release and at minimum zero containers. The height of the triangle is 1 divided by the mean, so that the surface of the triangle is equal to 100%. Figure 2 shows how the triangle looks like. Determining the number of container releases in this way ensures that there is no day-night pattern. This is one of the assumptions of this simulation model.

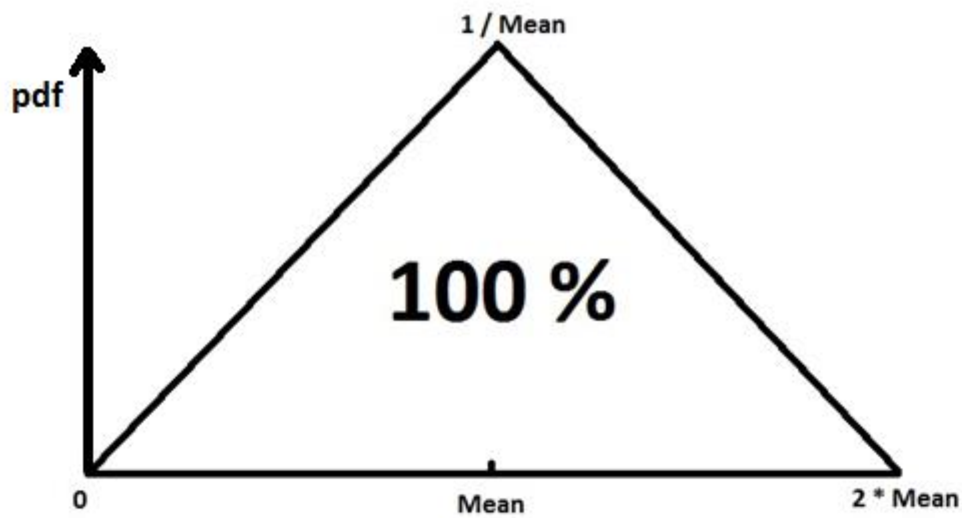

Figure 2: The triangular distribution (which is used to determine the number of ITT containers that release in one single hour)

As the amount of containers is always an integer, this triangular distribution should be discretized. This is simply done by rounding the values. This means that the whole area from

2.5 to 3.5 counts for three containers etcetera. The size of the surface of an integer decides the probability that that amount of containers is released in that hour at that origin terminal for that particular destination. On the basis of those probabilities and using a uniformly random number is decided how much container releases there are for an origin-destination pair in one single hour. The uniformly distributed random number decides which percentile is chosen and the area in which that percentile is indicates the amount of container releases. This is done for all origin-destination pairs, for all hours and optionally for all days.

After the amount of containers is decided for a single hour for an origin-destination pair, the exact release time and deadline for all containers separately should be decided. The exact release time is simply decided by drawing a random integer between 0 and 59, which indicates the minute of release in that hour. Now, only the deadline should be decided. This follows from the release time and the length of the window. There are three possible window lengths each with a probability, which can be found in table 1. Again, we draw a uniformly random number that decides the window length of a certain container.

	Length	Probability
Small window	2 hours	20%
Normal window	8 hours	30%
Large window	24 hours	50%

Table 1: The possible window lengths with their probabilities

Below a summary of this section that shows point wise how the data is generated:

First:

- Convert the yearly amounts of containers to daily amounts.

Then, for every origin-destination pair:

- Determine the mean number of container per hour and make the triangular distribution with 2 * mean as maximum and zero as minimum.
- Discretize the distribution, simply done by rounding.

At last, for every hour:

- Draw a uniformly random number that, together with the triangular distribution, decides the number of container releases in that hour.
- Draw a random integer between 0 and 59 that decides the minute of release in that hour.
- Draw a uniformly random number that decides the length of the window and thus the deadline.

2.1.1 Check the generated data

For the ITT problem of the Maasvlakte the container data is generated in the way described in the previous section. The matrix with the daily amount of ITT containers that should be transported between each origin-destination pair can be found in the appendix (table 10). For this problem we have generated four days, because Excel has enough rows for the data of the containers of this problem for four days. This section checks the generated data of the Maasvlakte problem with the way the data is generated.

First the window lengths are checked. These are generated so that 20% has a small window, 30% a normal window and 50% a large window. If we check the percentages of the windows from the generated data these percentages are very close to the real percentages which can be seen in table 2. This shows that the generation of the windows is done correctly.

	Real percentages	Generated percentages
Small window	20%	19.7%
Normal window	30%	29.9%
Large window	50%	50.4%

Table 2: Compare the real distribution of the windows with the generated distribution

The amounts of containers for transport are determined by the triangle distributions. For this we also check if the generated data is generated in a good way. The total number of containers in the matrix (table 10) with the daily amounts is 13,383. The generated data has a length of four days, so the amount of containers should be near (13,383 x 4) 53,532 containers. The generated data consists of 53,941 containers; this amount is close to 53,532. So, it seems that the amount of containers is also generated in a good way. To be sure, the amount if also checked for some random origin/destination pairs. For these pairs the generated amounts were very close to the real amounts. One example, in total 8,096 containers should leave terminal 1, while 8,330 containers are generated. Terminal 7 should have 2,952 containers ingoing, while there are 3,019 ingoing containers generated. At last, there should be 360 daily trips from terminal 1 to terminal 7. This means 1,440 trips in four days, while there are 1,513 trips generated.

The last thing to check from the generated data is the distribution of the release times of the containers over an hour. It is generated to be uniformly distributed. A histogram is made that shows for every minute in an hour (0 to 59) the amount of containers with the release in that minute. The histogram is shown in figure 3. If we look at this histogram we can see that all minutes have approximately an equal amount of container releases.

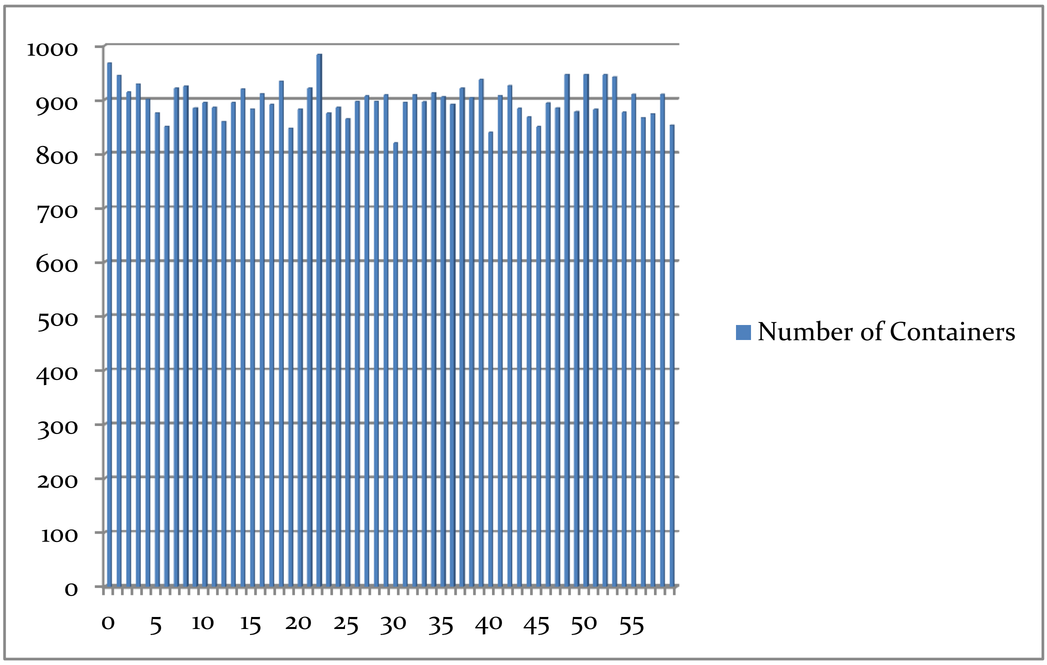

Figure 3: Distribution of the containers (from the generated data) over the minutes in an hour

This section ends with looking at the number of container releases over the time. This is not a check like in the previous paragraphs, but just to take a look at these container releases and find the hours of the day where there are more container releases than on average, so to find the so-called peaks. Figure 4 shows the average number of container releases per hour of the day.

If we take a look at this graph, we see that the average number of container releases differ not so much from each other for the different hours. Given the way the amount of container releases per terminal per hour is generated, it is indeed expected that there are no big differences in the number of container releases per hour. Still, we see a maximum and minimum. The maximum average number of container releases is 588.75, which is in the second hour of the day. The minimum is 528.25, which is in the 22^{th} hour of the day. Furthermore, there is one period of four consecutive hours with an average of more than 570 container releases. This period (10^{th}, 11^{th}, 12^{th} and 13^{th} hour) can be seen as a busy period.

	Hour(s) of the day	Average number of container releases
Busiest hour	2^{nd}	588.75
Quietest hour	22^{th}	528.25
Busiest period	10^{th}, 11^{th}, 12^{th} and 13^{th}	All > 570

Table 3: Hours with minimum and maximum number of container releases

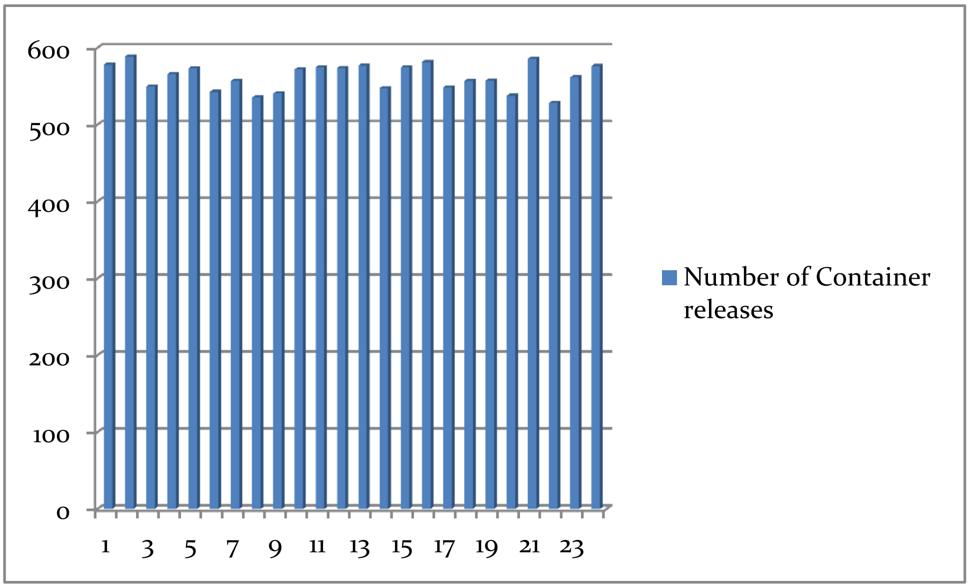

Figure 4: Average number of container releases per hour of the day

3. Planning and control of transports

The barges and trucks both have another way of traveling between terminals. Barges travel along the terminals according to a fixed route, while trucks travel on demand from terminal to terminal. Trucks travel to the destination of the container(s) they are carrying and after the containers are unloaded the trucks can be loaded with a container of every other terminal. So, the next destination of a truck is determined by the destination of the next available container.

This distinction between barges and trucks has to do with the fact that barges have a large capacity and trucks a small capacity. For barges it can be efficient to carry containers for terminal B while it is traveling first to terminal A and then to terminal B, because the barge can be loaded with containers for terminal A and terminal B so that the barge is faster fully loaded. For trucks it is not efficient to carry two containers which do not have the same destination. Trucks are already quick fully loaded, because of their small capacity. Then it is more efficient to load it with two containers with the same destination, because that saves travel time.

Barges should not be loaded with containers with a destination that is not visited very soon. For example, if there are nine terminals and a container is loaded at a terminal and the destination of the container is seven terminals later in the route, then it is almost impossible to deliver this container on time. Therefore, a maximum number of coming terminals should be chosen for which containers can be loaded at a terminal.

For example, assume that there are five terminals: A, B, C, D and E, and the route looks as follows: A -> B -> C -> D -> E -> A. Also assume that the maximum number of coming terminals whose containers can be loaded is two. This means that, if a barge is loading at terminal A, it can be loaded with containers for terminals B and C.

The order of the route of the barge is determined by searching for the shortest route, because this simply saves travel time. For the problem of the Maasvlakte this means the barges have the following route:

ECT ► DFDS Tor Line ► ECT Euromax ► BSC Bartelhaven ► Terminal Y ► Terminal X ►RWG ► APMT ► Common Barge SC ► **ECT**

Furthermore, for the planning and control of transport some decisions about inter alia, the order of loading and unloading of containers should be made. The rules based on these decisions are called decision rules and these can be found in section 4.2.

4. Simulation model

In this section the simulation model is explained. First, a description of the model and some information about the containers, vehicles and terminals are given. Then the decision rules that are used in the simulation are explained and this fourth section ends with the verification and validation of the simulation model.

4.1 Description of the model

The simulation model can be used in two ways, resulting in two main goals: to find the value of the penalty function for a fixed number of trucks or to find the minimum number of trucks such that (almost) all containers arrive on time. Ottjes et al. (1996) showed that from a certain moment increasing the number of trucks will give a very small decrease of the penalty, and sometimes it is not even possible to deliver all containers on time. That is why it may be better to take a certain value as limit. If the penalty value is smaller than the limit, the solution is good enough.

The simulation model uses a discrete time with time steps of one minute. This automatically means that all times that are used in the simulation are expressed in minutes. Also the inputs that have to do with times must be expressed in minutes. The simulation needs the following inputs:

- A matrix with the travel times for barges between terminals
- A matrix with the travel times for trucks between terminals
- A matrix with information about all ITT-containers. The matrix contains the following information about every container: origin, destination, release time and deadline.
- The duration of the simulation (simulation period)
- A vector with for every terminal the number of barges available at the beginning of the simulation
- The number of terminals that are attainable for barges
- (The number of trucks that are available for transporting ITT-containers during the whole simulation period)

Whether the last input is needed will depend on the main goal of the simulation. The simulation could be asked to calculate the penalty for a fixed number of trucks. In this case the last input is needed, but the simulation could also be asked to calculate the minimal number of trucks for which the penalty is equal to zero or less than the value of the limit. In this last case the last input is not needed.

For the three input matrices and the input vector the first terminals should be the barge terminals and these should be in the order of the route. As you can see in table 10, 11 and 12 in the appendix the first nine terminals are the terminals that are attainable for barges and these are in the order of the route, discussed in section 3. The reason for this is that because of the way the simulation is implemented, the simulation does not work if the barge terminals are not the first terminals in the matrix.

Before the simulation starts the trucks should be assigned to the terminals. The number of trucks that is assigned to a certain terminal is determined by the percentage of outgoing containers from the terminal with respect to all containers. The formula (1) that decides the number of trucks at the beginning of the simulation is shown below. The '% outgoing containers i' stands for the percentage of all outgoing containers that are outflowing containers for terminal i and that is multiplied with the total amount of trucks. This value can be a double, so it should be rounded. To precisely get the total number of trucks, for the last terminal the amount of trucks is the total amount of trucks minus the amount of trucks assigned to the other terminals.

$$Starting\ trucks\ at\ terminal\ i = \%\ outgoing\ containers\ i * amount\ of\ trucks \qquad (1)$$

As stated earlier, the simulation can be used in two ways. This results in two different types of output. If the simulation is used to find the value of the penalty function for a fixed number of trucks, the value of the penalty function is the output. This value indicates the total number of minutes that all containers together arrived too late.

In the other case the simulation is used to find the minimum number of trucks such that the value of the penalty function is smaller than the certain limit. In this case we start with one truck and run the simulation. If the penalty is lower than the limit (or equal to zero if no limit is used), one truck is enough to transport these containers and if the penalty is larger than the limit the number of trucks is increased by one. The simulation keeps increasing the number of trucks as long as the penalty value is larger than the limit and stops if the penalty is lower than the limit. Then the minimum number of trucks needed to deliver almost all containers on time is found and this amount will be the output of the simulation.

4.1.1 Containers

The simulation assumes that all containers have the same size (20 feet). This ensures that every container uses one unit of the capacity of a vehicle, which makes the simulation easier. Containers can be in two states: waiting for transport at the origin or loaded on a vehicle. After the container is delivered, it is no longer needed in the simulation and it will be removed from the system. About every container is known: the terminal of origin, the terminal of destination, the time at which the container is available for transport and a final delivery time.

4.1.2 Vehicles

Vehicles are able to transport containers from one terminal to another terminal. A Vehicle can be in three states: it is transporting, it is loaded / unloaded or it is waiting at a terminal. In the simulation two types of vehicles are used to transport all the ITT-containers from their origin to their destination. These are trucks and barges. Barges can transport large quantities of containers at once, while trucks can transport one, two or in some cases three at once. Another advantage of a barge over trucks is that waterways have mostly shorter connecting distances between terminals then roads. A disadvantage of barges with respect to trucks is that barges travel much slower.

Some assumptions about barges and trucks are made in the simulation. The capacity of barges is set to 50 containers, which is based on Tierney et al. (2012). The time of loading or unloading one container is set to one minute. Tierney et al. (2012) assumed that barges can load and unload containers, using two cranes, at a rate of 60 moves per hour, which is one minute per container. The rate at which barges travel is not determined within the simulation, because the travel times for barges between the terminals are one of the inputs. When creating the input-matrix with travel times between the terminals, the average speed of barges must be taken into account.

	Truck	Barge
Capacity	2 Containers	50 Containers
Load/unload time of one container	1 Minute	1 Minute

Table 4: Capacity and loading/unloading times of both vehicles

The capacity of trucks is set to two containers and the time of loading or unloading one container is, just as with the barges, set to one minute. The rate at which trucks travel is also not determined within the simulation, because the travel times for trucks are also one of the inputs. When creating the input-matrix with travel times between the terminals, the average speed of trucks must be taken into account.

4.1.3 Terminals

Terminals are the last objects that are present in the simulation. An assumption about terminals is that there are a finite number of locations at which containers are assumed available. This means that terminals are just points in the network (not a whole area). Terminals can be attainable for barges only, trucks only or both. As seen earlier, the travel times for barges and trucks between the terminals are one of the inputs of the simulation. At the terminals the containers that are waiting to be transported and the vehicles that are waiting to transport containers are present. A distinction is made between empty vehicles that are waiting to be loaded and the vehicles that are loading.

4.2 Decision rules

For the simulation of the transport of the ITT-containers some decision rules has to be made. For example, if a container is available for transport at a certain terminal and there are several barges and trucks available at the terminal, there should be a rule that decides on which vehicle the container will be loaded. In this section all decision rules are mentioned and explained.

- Order of loading and unloading of containers

The first decision rule describes which container should be loaded or unloaded first. For the loading of containers this is, when there are more containers waiting at a terminal for transport and there is a vehicle present. Which container should be loaded first? For the unloading of containers this is when a vehicle has arrived at its destination and is carrying more containers. Which container should be unloaded first? For both cases a very simple rule is used: if there are more containers, the container with the earliest due time is loaded or unloaded first.

- Decide on which vehicle a container should be loaded

The next decision rule is about the example mentioned earlier in this section. There must be a rule that decides on which type of vehicle the container is loaded if the destination of the truck is attainable for more than one vehicle type. If the vehicle type of the first choice is not available, then we look if there is a vehicle type of second choice available etcetera. Here we make a distinction between idle trucks and employed trucks. Employed trucks are trucks with at least one container on them and with space for another container. Idle trucks are empty trucks which are waiting for containers at a terminal. We make also a distinction between containers with a short remaining time till their due time and a large remaining time till their due time. These remaining times are not the same as the window lengths of the containers, because when a container is available at a terminal but there is no vehicle available it cannot be loaded immediately. In this case a small remaining time is shorter than 8 hours and a large remaining time is 8 hours or longer.

Containers with less remaining time should be delivered within a short time and so the vehicle should visit the destination of the container within a short amount of time. Therefore it is not a good idea to load this container on a barge, if this barge visits the destination of the container not directly after leaving the current terminal. The fastest way of transport is loading the container on an employed truck with the same destination. A truck which is loaded but not fully loaded has space for one more container, because in the simulation all trucks have a capacity of 2 containers. This means that if the container is loaded on this truck, the truck can leave immediately.

Now only the idle truck and the barge remain. The advantage of the empty truck is that a truck travels faster and the advantage of the barge is that the barge visits the terminal anyway. Here is chosen to give the barge priority, but not for all containers. If a container with a short remaining time is loaded whose destination is not the first terminal that is visited by the barge, then it is very difficult and sometimes even impossible to deliver this container on time. For this reason, containers with a short remaining time can only be loaded on a barge if their destination is the next terminal that is visited by the barge. For containers with much remaining time is chosen that these can only be loaded on a barge if their destination if one of the next three terminals that are visited by the barge.

The next vehicle is the idle truck. If no employed trucks are available at the terminal and no barge is available or the barge visits the destination of the container not soon enough, the container is loaded on an idle truck if there is one available. If there are no vehicles present at the terminal, an empty truck from another terminal will travel to this terminal to transport the container. How these empty trips are generated is explained in the next decision rule.

In the case that there are so called 'fixed trips', which are trips (by barge or truck) between two terminals at certain times, these vehicles are loaded first. These trips are needed to see what the effect is of the uncertain connections. Table 5 shows a summary of the order of vehicle choice for the different sizes of container windows.

	Remaining time till due time < 8 hours	**Remaining time till due time > 8 hours**
(0)	Fixed trips	Fixed trips
1	Employed truck	Employed truck
2	Barge (next destination)	Barge (next 3 destinations)
3	Idle truck	Idle truck
4	Empty truck from another terminal	Empty truck from another terminal

Table 5: Order of vehicle choice for a container depending on the remaining time till the due time of the container

- Empty trips

Most of the terminals will not have an equal inflow and outflow of containers so that after some time there is a surplus or shortage of vehicles at most of the terminals. This ensures that sometimes vehicles should travel empty from one terminal to another terminal, so called empty trips. Empty trucks are only done by trucks.

The previous decision rule shows how to load a container, but if there is no vehicle available to transport the container, the container is not loaded. In this case a vehicle should visit this terminal very soon to be sure that this container is visited on time. First, the traveling vehicles are checked whether one of these is traveling to this terminal. If so, this vehicle will arrive at the terminal very soon and will be able to deliver the waiting container on time. If none of the traveling vehicles is traveling to the terminal with the waiting container, an idle truck from another terminal should travel empty to this terminal. Then the question remains: From which terminal will the empty truck come?

The most logical solution is to let the truck come from the terminal with the most overcapacity. So, for every other terminal is checked how much 'idle trucks' there are available at this moment in comparison with the number of trucks available at the beginning of the simulation. The terminal with the most available 'idle trucks' in comparison with the strating number of trucks will send an empty truck to the terminal without trucks.

- Departure of a vehicle

If a container is loaded on a vehicle and the vehicle is not fully loaded we should decide whether it waits for a next container or that the vehicle will leave immediately. For the problem of the Maasvlakte is chosen for a maximum waiting time for a truck of ten minutes. This means that if the first container is loaded on a truck and another container is available or will be available in the next ten minutes, the truck will wait for the second container. If not, the truck leaves immediately. A barge will wait at maximum one hour after the last container is unloaded at that terminal. The barge leaves the terminal if it is waiting exactly one hour or if the filling degree is greater than 2/3.

	Truck	Barge
Maximum waiting time	10 Minutes	60 Minutes
Minimum filling degree	Full	2/3

Table 6: Maximum waiting time and minimum filling degree per vehicle type

4.3 Verification and validation

In this section the verification and validation of the simulation is done. The result of the simulation (amount of trucks needed) is compared with the result of a simple benchmark model for a small problem.

The simple problem consists of:

- Five terminals
- Daily amount of transporting containers between each origin/destination pair of at maximum hundred.
- Duration of two days
- No barges

The benchmark model is based on trucks that travel between two terminals. If a truck is at a terminal and there are containers available for transport these containers are loaded on the truck (with a maximum of two) and if there are no containers available at the terminal the truck will travel empty to the other terminal. So, for each pair of terminals is calculated how much trucks are needed to transport all containers between the two terminals on time. All these trucks are added to each other and this amount is the benchmark.

The amount of trucks calculated via the benchmark model for this simple problem was 9. When we ran the simulation for this simple problem it gave 7 trucks as output with a penalty of zero, which implies that all containers can be delivered on time using 7 trucks. The fact that the amount of trucks needed to deliver all containers on time is lower for the simulation model than the benchmark model indicates that the simulation model is working well.

5. Results of the Maasvlakte ITT-problem

In this section the results of the several simulation runs for the ITT-problem of the Maasvlakte are shown and discussed. The running time of one single run is about 50 seconds. The next runs (if the simulation is searching for the minimum amount of trucks needed) have a runtime of a few seconds. This is because most of the time of the first simulation is reading the input file, and for the next runs the file is already read in the first simulation.

The most important thing to compare the results is the number of trucks that are needed to transport almost all containers on time. As discussed earlier, from a certain moment increasing the number of trucks will give a very small decrease of the penalty, and sometimes it is not even possible to deliver all containers on time. For this problem this is not the case, which is the reason that there is chosen that all containers should arrive on time. Further, it is assumed that trucks travel with an average speed of 50 km/h and that barges travel with an average speed of 10 km/h. This resulted in the tables 11 and 12 (see appendix), which show the travel times between the terminals for trucks and barges respectively.

Besides, the simulation also keeps up some performance measures:

- Percentage of containers transported by trucks
- Percentage of containers transported by barges
- Percentage of containers transported by fixed trips
- Busy truck percentage
- Average utilization rate of a truck
- Average utilization rate of a barge

The 'busy truck percentage' is the percentage of the total time that trucks are busy, which means that they are traveling or loading/unloading. The other performance measures speak for themselves, so that for these no explanation is necessary.

First, several simulation runs are done to check for a good amount of barges for this problem. The results of these runs with different amounts of barges are shown below in table 7.

No fixed trips	Amount of trucks needed	% transported by trucks	Average utilization rate of a truck	Average utilization rate of a barge	% of total time that trucks are busy
0 Barges	92	100.00%	79.97%	-	74.51%
1 Barge	91	99.92%	79.88%	0.50%	74.88%
3 Barges	**89**	**99.82%**	**80.10%**	**0.36%**	**74.48%**
9 Barges	88	99.54%	80.08%	0.30%	74.89%
18 Barges	88	99.19%	80.10%	0.27%	74.56%
90 Barges	85	96.66%	80.60%	0.22%	75.95%

Table 7: Results of the simulation without fixed trips

If we look at table 7 we see that almost all containers (for all different amounts of barges used) are transported by trucks and that the utilization rate of barges is very low. The reason for this is that the hourly containers flows between the terminals attainable for barges are not large enough. Thereby not much containers are loaded on barges and thus the number of containers transported by barges is low. After one hour waiting barges leave the terminal, so most times barges will leave a terminal with not much containers loaded on them, which results in a very low utilization rate.

The idea is to compare the results from table 7 with the results of simulation runs where there are 'fixed trips' present. These trips are trucks or barges that are present only between two fixed times. These trips represent the uncertain connections, because in one simulation these are not present and in the other simulation these are present. To compare the results of the simulation without the fixed trips with the simulation results of several variants of fixed trips, we need to choose a fixed amount of barges. As we can see in table 7, the results do not differ that much from each other. We chose for three barges, because from that point increasing the number of barges will not save many trucks. For example, using 90 barges will save only 4 trucks instead of using 3 barges. These three barges are evenly distributed at the beginning of the simulation; they start at terminal one, four and seven.

The simulation with the fixed trips is first run for fixed trips between the two busiest terminals, terminals fifteen and one. Several runs are done with different situations, which differ from each other in the number of free trucks that are available, the period of the day that these trucks are available and the length of this period. Runs are done with one truck, ten trucks or thirty trucks. If there are more trucks used, half of them will start at terminal one and the other half at terminal fifteen. The different periods that are used are: the busiest hour, the quietest hour and the busiest period (see table 3). The results of these runs are shown in table 8.

If we take a look at table 8 and compare the results with the simulation (with three barges) without the fixed trips we see that one free truck in the busiest hour or in the busiest period does not make sense, but using ten free trucks in one of these periods will decrease the total number of trucks needed with one. For the quietest hour, even using thirty free trucks does not make sense. This is logical, since there are not much containers to transport for these free trucks in the quiet hour. All in all the amount of trucks needed can be decreased by one, using ten free trucks, but the impact of free trucks is small because at maximum (thirty free trucks in the busy period) 0.54% is transported with free trucks.

Fixed trips	Amount of trucks needed	% transported by trucks	Average utilization rate of a truck	Average utilization rate of a barge	% of time that trucks are busy	% transported by free trucks
1 (Quiet hour)	89	99.76%	80.06%	0.39%	74.20%	0.04%
10 (Quiet hour)	89	99.75%	80.10%	0.41%	74.49%	0.05%
30 (Quiet hour)	89	99.76%	80.09%	0.34%	74.20%	0.06%
1 (Busy hour)	89	99.73%	80.07%	0.41%	74.32%	0.06%
10 (Busy hour)	88	99.70%	80.11%	0.40%	75.28%	0.10%
30 (Busy hour)	88	99.73%	80.04%	0.33%	75.28%	0.10%
1 (Busy period)	89	99.61%	80.12%	0.39%	74.15%	0.19%
10 (Busy period)	88	99.34%	80.05%	0.42%	74.80%	0.45%
30 (Busy period)	88	99.24%	80.03%	0.43%	74.75%	0.54%

Table 8: Results of the simulation runs with fixed trips between terminals 15 and 1

For the next simulation runs we assume that the busiest terminals (one and fifteen) have trucks present between certain times, which can travel from and to this terminal. For example, a truck that starts at terminal one can travel to any other terminal, but when the truck is there it has to travel (empty or loaded) back to terminal one. For these runs only the busiest hour and period are used, because the quietest hour will have much less influence as we have seen in table 8.

The results of these simulations are shown in table 9. Using twenty trucks will give almost the same results as using ten or thirty trucks between these two terminals for both periods. Therefore a much higher amount is chosen (120 and later 400) to look if the amount of trucks needed can be decreased. Table 9 shows that this is not the case. Even using 400 trucks per terminal in the busy period will not decrease the amount of trucks needed to 87 or lower. An explanation for this can be that in the period that these free trucks are not present 87 trucks are not enough to ensure that all containers are delivered on time. This means that if there are just a few uncertain connections (only between two terminals, or from and to one or two terminals) the amount of extra trucks that are needed differ not much. What we also see is that for all simulation runs that we have done the utilization rate of trucks is around 80%, the utilization rate of barges around 0.40% and trucks are around 74% of the total time busy with the transport of containers.

Fixed trips	Amount of trucks needed	% transported by trucks	Average utilization rate of a truck	Average utilization rate of a barge	% of time that trucks are busy	% transported by free trucks
20 (busy hour)	89	99.38%	80.06%	0.39%	74.24%	0.42%
20 (busy period)	88	97.61%	79.80%	0.42%	74.26%	2.18%
120 (busy hour)	88	99.25%	80.00%	0.41%	74.86%	0.55%
120 (busy period)	88	97.10%	79.68%	0.38%	73.97%	2.71%
400 (busy hour)	88	99.25%	80.02%	0.40%	74.84%	0.55%
400 (busy period)	88	97.13%	79.63%	0.38%	73.99%	2.67%

Table 9: Results of the simulation runs with fixed trips from terminals 1 and 15

6. Conclusion

This thesis describes a way of transporting ITT transport between terminals for the extended Maasvlakte in the port of Rotterdam. This way, called asset-light solution, assumes that residual capacity of visiting trucks can be used to transport a part of the ITT containers. In addition to these visiting trucks with residual capacity and the use of a fixed number of barges should be determined how much extra trucks are necessary to ensure that all ITT-containers are delivered on time. The first part of the thesis showed how the data is generated and how the simulation model works. In the last part the simulation is run several times (with different inputs) and the results of these simulations are compared with each other.

To say something about the uncertain connections, the results of the simulation with and without some fixed trips are compared with each other. What struck is that for all simulation runs with three barges the amount of trucks needed was 88 or 89, while several different variants of fixed trips are used. An explanation for this can be that in the period of the day that these fixed trips are not present; at least 88 trucks are needed to ensure that all containers are delivered on time. For this problem of the Maasvlakte this means that if there are not too much different uncertain connections the amount of extra trucks needed is approximately the same for the case where the uncertain connections are available and for the case where these uncertain connections are not available. In this case it will make it easy to predict the number of extra trucks needed in the presence of uncertain connections, but on the other hand it makes the usage of residual capacity of visiting trucks useless.

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Appendix

Terminals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ECT 1	0	0	38	360	38	38	38	38	37	186	424	373	17	97	205	0	0	0	0
DFDS Tor Line 2	0	0	0	29	0	0	0	0	29	7	7	0	0	0	0	0	0	0	0
ECT-euromax 3	26	0	0	48	26	26	26	26	37	186	53	0	17	97	0	193	0	0	0
BSC Bartelhaven 4	360	29	48	0	48	48	48	48	0	0	0	0	0	0	96	13	0	0	0
Terminal Y 5	17	0	17	48	0	17	17	17	110	186	53	0	17	35	0	48	0	0	0
Terminal X 6	15	0	15	48	15	0	15	15	110	186	53	0	17	19	205	0	0	0	0
RWG 7	23	0	23	48	23	23	0	23	110	186	53	47	17	60	205	0	0	0	0
APMT 8	43	0	43	48	43	43	43	0	37	186	424	47	17	112	205	0	0	0	0
Common Barge SC 9	37	29	37	0	37	110	110	110	0	0	0	0	0	0	144	39	0	0	0
Common Railway Ter. 10	186	7	186	0	186	186	186	186	0	0	0	47	0	0	58	16	0	0	0
RTW-MV1 11	424	7	53	0	53	53	53	424	0	0	0	47	0	0	39	5	0	0	0
Kramer 12	373	0	0	0	0	0	47	47	0	47	47	0	0	8	0	0	0	0	0
Douane scan 13	17	0	17	0	17	17	17	17	0	0	0	0	0	0	0	0	0	0	0
Distripark Maasvlakte 14	0	0	0	4	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
ED1 15	503	0	0	24	0	503	503	503	36	14	10	0	0	0	0	0	0	0	0
ED2 16	0	0	450	3	112	0	0	0	3	1	1	0	0	0	0	0	0	0	0
Chemie nieuw E 17	0	0	0	0	0	0	0	0	0	19	19	0	0	0	0	0	0	0	0
Chemie nieuw K1 18	0	0	0	0	0	0	0	0	0	13	13	0	0	0	0	0	0	0	0
Chemie nieuw K3 19	0	0	0	0	0	0	0	0	0	12	12	0	0	0	0	0	0	0	0

Table 10: Amounts of containers that should be transported on the Maasvlakte for each origin-destination pair in one single day

Terminals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ECT 1	0	8	22	3	14	12	12	7	13	7	4	3	4	6	7	20	6	14	11
DFDS Tor Line 2	8	0	25	6	17	15	14	10	15	9	6	6	6	9	10	23	3	17	14
ECT-euromax 3	22	25	0	20	9	14	13	15	14	16	19	20	19	17	15	3	22	9	12
BSC Bartelhaven 4	3	6	20	0	12	10	10	5	10	4	2	1	1	4	5	18	3	12	9
Terminal Y 5	14	17	9	12	0	6	5	8	6	8	11	12	11	9	8	7	15	1	5
Terminal X 6	12	15	14	10	6	0	1	6	1	6	9	10	9	7	6	12	12	6	2
RWG 7	12	14	13	10	5	1	0	5	1	6	9	10	9	6	5	11	12	5	1
APMT 8	7	10	15	5	8	6	5	0	6	1	4	5	4	2	1	13	8	8	4
Common Barge SC 9	13	15	14	10	6	1	1	6	0	7	10	11	10	7	6	12	13	6	2
Common Railway Ter. 10	7	9	16	4	8	6	6	1	7	0	4	5	4	1	1	14	7	8	5
RTW-MV1 11	4	6	19	2	11	9	9	4	10	4	0	2	1	3	4	17	4	11	8
Kramer 12	3	6	20	1	12	10	10	5	11	5	2	0	2	4	5	18	4	12	9
Douane scan 13	4	6	19	1	11	9	9	4	10	4	1	2	0	3	4	17	4	11	8
Distripark Maasvlakte 14	6	9	17	4	9	7	6	2	7	1	3	4	3	0	2	15	6	9	6
ED1 15	7	10	15	5	8	6	5	1	6	1	4	5	4	2	0	13	8	8	4
ED2 16	20	23	3	18	7	12	11	13	12	14	17	18	17	15	13	0	20	7	10
Chemie nieuw E 17	6	3	22	3	15	12	12	8	13	7	4	4	4	6	8	20	0	15	11
Chemie nieuw K1 18	14	17	9	12	1	6	5	8	6	8	11	12	11	9	8	7	15	0	5
Chemie nieuw K3 19	11	14	12	9	5	2	1	4	2	5	8	9	8	6	4	10	11	5	0

Table 11: Travel times for a truck (50 km/h) in minutes for each origin-destination pair

Terminals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ECT 1	0	31	42	72	72	72	84	85	47	0	0	0	0	0	0	0	0	0	0
DFDS Tor Line 2	31	0	14	44	44	44	56	57	52	0	0	0	0	0	0	0	0	0	0
ECT-euromax 3	42	14	0	34	35	35	46	47	63	0	0	0	0	0	0	0	0	0	0
BSC Bartelhaven 4	72	44	34	0	4	4	44	46	92	0	0	0	0	0	0	0	0	0	0
Terminal Y 5	72	44	35	4	0	5	45	46	93	0	0	0	0	0	0	0	0	0	0
Terminal X 6	72	44	35	4	5	0	45	46	93	0	0	0	0	0	0	0	0	0	0
RWG 7	84	56	46	44	45	45	0	5	104	0	0	0	0	0	0	0	0	0	0
APMT 8	85	57	47	46	46	46	5	0	106	0	0	0	0	0	0	0	0	0	0
Common Barge SC 9	47	52	63	92	93	93	104	106	0	0	0	0	0	0	0	0	0	0	0
Common Railway Ter. 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RTW-MV1 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kramer 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Douane scan 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distripark Maasvlakte 14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ED1 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ED2 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemie nieuw E 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemie nieuw K1 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemie nieuw K3 19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12: Travel times for a barge (10km/h) in minutes for each origin-destination pair (some terminals are not attainable for barges, all travel times of these terminals are zero)