Inter-terminal transport on Maasvlakte 1 and 2 in 2030

Towards a multidisciplinary and innovative approach on future inter-terminal transport options

Deliverable 3.1

Determining the cost savings for the participants in a joint inter terminal transport system at the Port of Rotterdam

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Determining the cost savings for the participants in a joint inter terminal transport system at the Port of Rotterdam

Master Thesis Supply Chain Management

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Summary

With the construction of the Maasvlakte 2 area in the Port of Rotterdam, the number of container terminals and container handling capacity increases. The Port Authority set ambitious goals to shift container transportation from road, and therefore reducing road congestion, to barge and rail transportation. Container flows to Hinterland destinations get scattered, due to arrival on different terminals in the port area. A system of inter terminal transportation (ITT) can bundle container flows to reach the modal split goals of the Port Authority. The question is what cost savings could be obtained by the participants for a joint inter terminal transportation system. Demand scenarios are created to get insight in the flows between the participants. The performance of three solutions, a shared pool of trucks, automated guided vehicles and multi trailer services, is analyzed by a simulation model. The cost of each coalition for each solution is analyzed with the help of game theory.

The demand scenarios for inter terminal transport for the year 2030 differ between 1.42 million TEU and 3.34 million TEU. The main container flows are between deep sea terminal and barge or rail facilities. A large container flow comes from the transportation of empty containers to and from empty depots. The current situation in the port is analyzed to deduct a peak factor in the container demand scenarios.

The demand scenarios and layout of the terminals is input for the simulation model. The simulation model generates containers according to the different demand scenarios. The containers are loaded onto transporters and travel to the container destination. Three types of transporters are simulated, namely trucks with capacity of 2 TEU, automated guided vehicle and multi trailer services with a capacity of 10 TEU. A dispatching rule is applied that steers empty transporters to terminals with many containers waiting, short distance to the current position of the transporter and container with short due times. The model is able to determine the number of transporters required to deliver the containers. The number of kilometers driven, the driver time and the penalty time for late containers are results from the simulation. These results are input for the cost function to determine the yearly cost of inter terminal transportation. The cost function distinguish between different type of transporters. The simulation model is used to analyse the cost of coalition consisting of different players. The cost are analysed to determine the contribution of each player to the total cost savings.

The results show that the cost of individual transportation is always higher than a collaboration of all players. The truck and AGV require 70 transporters for scenario 1, 41 transporters for scenario 2 and 27 transporters for scenario 3. An ITT system transporting containers with MTS with a capacity of 10 TEU requires 60 transporters for scenario 1, 36 transporters for scenario 2 and 24 transporters for scenario 3. The automated guided vehicle is the most cost effective solution for inter terminal transportation, because of the reduction of wage cost. The total yearly

cost of an AGV solution is 9.5 million for scenario 1, 6.0 million for scenario 2 and 3.9 million for scenario 3. The cost of the manned transporters is in the same range. The cost of a pool of shared trucks is 21.5 million, 12.9 million and 8.7 million for scenario 1, 2 and 3 respectively. In the case of the MTS the cost for the scenarios 1,2 and 3 are 21.2 million, 13.8 million and 9.4 million. The MTS is favoured in the high demand scenario over the truck.

The coalitions were rail and barge facilities are included are crucial to obtain cost savings. The cost savings should be allocated to the players that own these facilities. The results show that the players 1 and 4 contribute the most to the cost savings in a coalition, followed by player 5. The Port of Rotterdam Authority should identify the importance of the commitment of player 1 and 4 early in the ITT system design process. For a shared truck configuration, a benefit allocation can be found that holds individual rationality. In the case of AGV and MTS, individual rational benefit allocations are difficult or not existent. To value the important players, the Port of Rotterdam Authority can assign a larger proportion of the cost savings.

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Chapter 1 Introduction

The construction of the "Maasvlakte 2" creates space to add four deep sea terminals to the Port of Rotterdam. The additional terminals will more than double the container handling capacity. The containers have to be transported to the Hinterland with the existing infrastructure. The Port of Rotterdam Authority set ambitious goals to shift the Hinterland transportation from road to barge and rail. The growth will be accommodated by rail transportation, for example the "Betuweroute", and available capacity at the waterways (Dutch Inland Shipping Agency, 2007). To reduce the share of road transportation, bundling of small container flows is required. The bundling of small container flows in the port area can be facilitated by an inter terminal transport system.

Inter Terminal Transport (ITT) is the transport between deep sea-, rail- and barge terminals and empty depots in the port. The ITT system services mainly two container handling activities namely: the bundling of containers and second-tier container services. By bundling, the frequency of Hinterland connections can be increased. More frequent Hinterland connections lower the boundary to shift away from road transportation. Independent deep sea terminals cannot offer these connections for low volume Hinterland destinations. Second-tier container services like repair, custom clearance, pre-voyage check or empty storage, require transportation of containers within the port area. These short distance moves can be executed by the ITT system and therefore reduce road congestion in the port area.

The ITT system can be realized in many different shapes. The ITT system will only prosper when the deep sea terminals collaborate. Deep sea terminals will have a higher incentive to collaborate when the ITT system leads to cost savings. This study determines the cost savings for participants in a joint ITT system. Insight in the cost savings, allows the Port Authority to create conditions for participants to perform ITT cooperatively.

1.1 Literature review on container operations

The Port of Rotterdam expands to the west with the construction of the Maasvlakte 2 (MV2), which will add 680 hectares of land and 3 km of quay wall for container operations. Container terminals will be built in two phases. In the first phase, new container terminals of APM and Rotterdam World Gateway become operational (Port of Rotterdam Authority, 2013). The number of containers handle in TEU (twenty feet equivalent unit) raises from 11.8 million TEU (Port of Rotterdam Authority, 2012b) to around 30 million TEU (Port of Rotterdam Authority, 2011a).

Vis and De Koster (2003) describe the decisions to be made the different control levels: strategic, tactical and operational. The decision horizon of strategic decisions is more than one year and has typically to do with the lay-out of the terminal and selection of material handling equipment. Tactical level is between days and months. An example of a tactical decision problem is the stacking of containers. Finally, at the operational level the daily planning and problem solving is done.

The handling of containers of ocean going vessels takes place at deep-sea terminals. In automated terminals, containers are transported between the crane and the stack by use of Automated Guided Vehicles (AGV) and containers are automatically placed in the stack by use of Automated Stacking Cranes. Every deep-sea terminal has dedicated connections with the hinterland through feeders, inland shipping, rail terminals and road terminals. A classification of terminal sub processes is used to understand the terminal operations. The load and unload process at a terminal can be divided in seaside, internal transport, stacking area and landside (Figure 1).

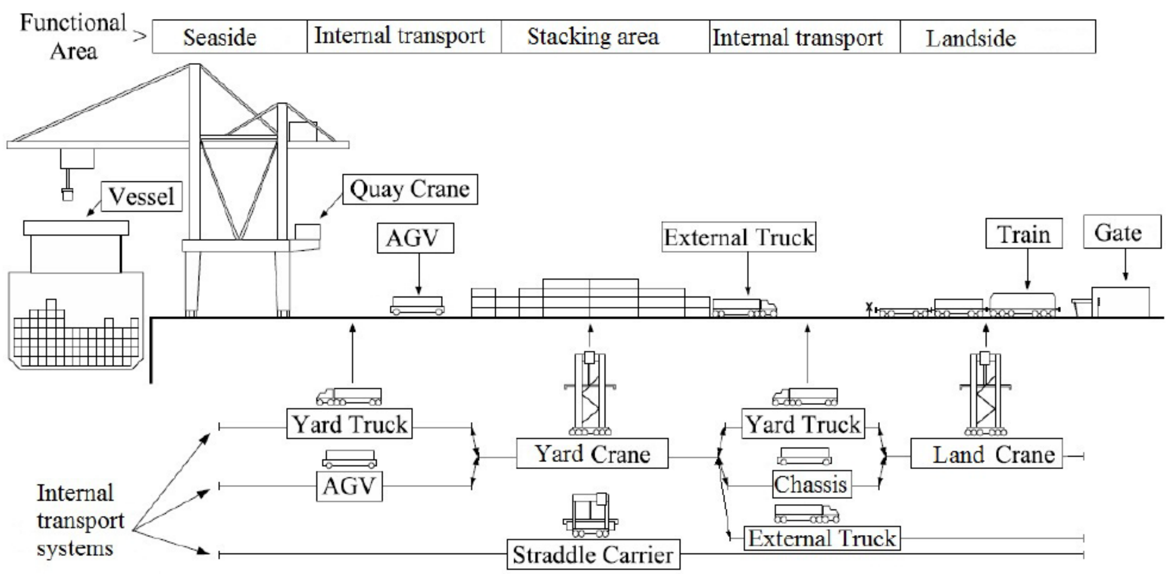

Figure 1: Loading and unloading processes of containers at a typical container terminal (adapted from (Gharehgozli et al., 2013))

The internal transport is the transport of containers from the quay crane to the stack and from the stack to the landside of the terminal. Different types of vehicles are used for internal transport, among them are single or multi-trailer carriers, straddle carriers, automated straddle carriers, automated guided vehicles and lift automated guided vehicles. The objectives for typical operations research models (Gharehgozli et al., 2013) for internal transport are to determine the optimal fleet size and vehicle routing.

The stack decouples the seaside of the terminal from the landside of the terminal (Steenken et al., 2004). A container will be delivered by internal transport to the input point of the stack. The

yard crane places the container in the stack. In the case of a retrieve order, the yard crane places the container at the output point of the stack and the container will be transported by internal transport. A good stacking policy reduces the further need of reshuffling the stack.
The landside transport aims to get the container at the right time ready for transportation to the Hinterland. Large container terminals serve some thousands of trucks and many trains per day. The trucks arrive at the gate of the terminal with the pick-up data. Once at the terminal, the truck drives to a transition point where a container is loaded on the truck. Trucks have a time slot to pick up containers and the terminal has to balance the load that all trucks are served within acceptable times.

Due to the increase of container transport, the role of container terminals in networks changes. Deep-sea terminals face challenges with congestion, the environment and delays. The scarcity of land in the port area pressures non-critical handlings like for example the cleaning and inspection of containers, to the hinterland. Another example is the notion of dry ports (Zuidwijk et al., 2012), terminals offering custom clearance and transportation to the Hinterland. The design of a barge service center is described by Zuidgeest (2009).

The first study was done to investigate the different types of transport equipment for the MV1 in 2005 (Ottjes et al., 1996, Duinkerken et al., 2006). The study is based on an estimated demand of containers of 1.4 million. The study did not take the MV2 into account. The objective of the study was to measure the percentage of late containers. A very detailed simulation model determined that 120 AGV's results in 0.1% of late containers. For MTS, the lateness was equal to 0.5%. The study showed that increasing the handling capacity can reduce lateness of containers.

A recent contribution is the optimization model of Tierney et al. (2012). An integer programming model was created and applied to several scenarios for the port of Hamburg and the Port of Rotterdam. The optimization model gives a lower bound for the number of vehicle to be used in the ITT system. Congestion of crossings is programmed with time-space nodes. The model is able to find the optimum when two types of transporters are applied. Simulating a 6 hour time period, the number of containers arriving too late in the model is equal to 7.5%. When large number of containers are assumed, the model has difficulties to be solved.

Diekman and Koeman (2010) estimated the cost of different ITT options for the Port of Rotterdam Authority. The report includes different transporters and a cost analysis. However, the results are not based on a simulation and therefore difficult to interpret. Congestion and lateness of containers are not considered. The previous studies on ITT do not include the behaviour of individual participants. Every study assumes that all participants will collaborate. This study will determine the cost savings for individual players based on game theory.

1.2 Game theory concepts and an example problem

Game theory is a mathematical tool about interactive decision situations. Each player is dependent on the moves that other players in the game make. A distinction can be made between cooperative and non-cooperative game theory. Cooperative game theory assumes that a group of players want to perform a joint project. In a transferable utility game, the cost or gain from the game can freely distributed between the players of the game (Miras Calvo and Sanchez Rodrıguez, 2006). The purpose of cooperative game theory is to define and allocate to each player individually the benefits of joint cooperation. An extensive literature review about cost allocations in cooperative game theory is done by (Fiestras-Janeiro et al., 2011). By deciding the how much every player has to pay for the ITT system, the cost of the ITT system is distributed over the players. The payment scheme for the ITT system should cover the costs, but must be perceived fair by each player. If the payment scheme is not fair, that player will abandon the coalition and perform the ITT transport by themselves.

This paragraph explains concepts from the game theory that will be applied to the ITT problem. The concepts will be explained by a three-person example problem (Leng and Parlar, 2005).

In a three-person game, there are 2^N (8) possible coalitions, where N is the number of players in the game. The example problem can be described by the characteristic function: A=(v(1) v(2) v(12) v(3) v(13) v(23) v(123)). The characteristic function describes the possible coalitions. The characteristic function summarizes the payoff vector of the game. The payoff is the gain obtained from working together in a coalition. In the example problem, the payoff are the following: v(1) = v(2) = v(3) = 0; v(12) = 2; v(13)=4; v(23)=6 and v(123)= 7. The coalition with all players included is called the grand coalition N. Take the coalition S {1,3} and T {2,3} then the coalitions $S \cup T$ is {1,2,3} and $S \cap T$ is {3} from the 2^N coalitions.

A game is super additive when $v(S \cup T) \geq v(S) + v(T)$. A super additive game has an increasing payoff vector when more players are added to the coalition. So adding an extra player to the coalition will always result in a cost advantage for the coalition. The example game is an additive game.

A game can be checked on monotonic behaviour. A game is monotonic if $v(S) \leq v(T)$ for each coalition $S \subset T$. This means that there are no payoffs possible where for example $v(1) \leq v(12)$. Adding any player to the coalition will lead to a cost reduction. The example game is monotonic.

Furthermore a game can be checked on convexity. A game is convex if:

$$v(S \cup T) + v(S \cap T) + \geq v(S) + v(T)$$

The example game is not convex because $v(123) + v(3) \geq v(13) + v(23)$ is not true ($7+0 \geq 4+6$). In a convex game, the incentive to join the coalition grows when the coalition size grows.

If the payoff of the grand coalition is equal or more than the payoff of any other coalition then the game is essential. $\sum_{i=1}^{n} v(i) \leq v(N)$. If the payoff of the grand coalition is equal to the payoff of the grand coalition, then the game is degenerative. $\sum_{i=1}^{n} v(i) = v(N)$. Every degenerative game is also essential. The example problem is essential but not degenerative.

An imputation $(x = (x_1, \dots x_{n)})$ is the allocation of the payoff to each individual player. An imputation is called efficient if all value is distributed over the players. $v(N) = x_1 + \cdots + x_n$ Important in the allocation is the individual rationality. If the payoff for a player is equal or more than the payoff assigned by the imputation, the imputation is in the Core. The Core (Gillies, 1953, Shapley, 1971) is the set of all un-dominated payoffs to the participant satisfying rationality properties (Meirvenne, Van, 2012).

$$C(N,v) = \{x \in I(N,v): \sum_{i \in S} x_i \geq v(S)$$

Figure 2 shows the set of possible imputation and the Core. For problem with more than four players it is not possible to represent the Core geographically. The Core can also be empty when no solution holds individual rationality.

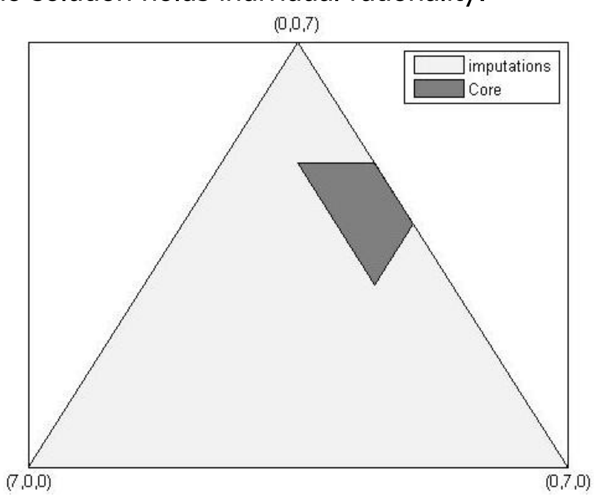

Figure 2: The core of the three-person example problem

For the utopia payoffs of the game (N,v), the maximum payoff is:

$$M_i(N,v) = v(N) - v(N\{i\})$$

The minimum utopia payoff is:

$$m_i(N,v) = \max_{S:i \in S}\{v(S) - \sum_{j \in S\{i\}} M_j(N,v)\}$$

To verify that a game is compromise admissible the following conditions have to be met: $m(N,v) \leq M(N,v)$ and $\sum_{i=1}^{n} m_i(N,v) \leq v(N) \leq \sum_{i=1}^{n} M_i(N,v)$

In the example problem M is equal to [1 3 5] and m is equal to [0 1 3]. The example problem is admissible compromise.

The tau-value calculates an imputation according to the following formula:

$$\tau(N,v) = m(N,v) + \alpha(M(N,v) - m(N,v))$$

Where $\alpha \in R$ and $\sum_{i \in N} \tau_i(N,v) = v(N)$

The tau-value can only be calculated when the game is compromise admissible and creates an imputation that lies in the Core. The tau-value divides all possible gain of the game. For the example problem, the tau-value is [0.6 2.2 4.2].

The nucleolus is an imputation that minimized the maximum complaint of all coalitions. In the case that the core is non-empty, the nucleolus is in the core. For an allocation x, the excess of a coalition S is defined as: e(x,S) = v(S) – x(S). If then e(x) is a vector of excesses in decreasing order, the nucleolus is then the imputation $\eta \in I(v)$ such that $e(\eta) \leq_{lex} e(x)$ for all $x \in I(v)$. In the case of the example problem, the nucleolus is [0.5 2.25 4.25]. with excess of v(1)= -0.5; v(2)= -2.25; v(3)= -4.25; v(12)= -0.75; v(13)= -0.75 v(23)= -0.5; and v(123) = 0.

For more than 4 players the nucleolus (Schmeidler, 1969) is difficult to calculate because it involves multiple linear programming optimizations. Therefore the nucleolus will not be used to analyse the ITT system.

The Shapley value (Shapley et al., 1953) is the cost allocation that satisfies symmetry, null agent property and additively. If two players have symmetric roles, the value assigned to these players should be the same. In the case a player does not add to the coalition (null agent property) the assigned value is zero. In the case that there are the same players in a coalition, the value assigned must be the same as the sum of two individual coalitions with the same players. Or $v(S+T) = v(S) + v(T)$. The Shapley value is a unique cost allocation value and all the value will be distributed.

The Shapley value does not have to be in the core. The Shapley value Φ_i is given by:

$$\Phi_i = \sum_{i \in S} \frac{(|S|-1)!\,(|N|-|S|)!}{|N|!} (v(S) - v(S-i))$$

Where:

$|N|$ is the number of players in the grand coalition and $|S|$ is the number of players in the coalition. For the example problem, the Shapley value is equal to [1.33 2.33 3.33]. In the example problem is the Shapley value in the core.

There are many examples of studies were the cooperative game theory is applied. A classic example is the airport problem (Littlechild and Thompson, 1977). The objective of the study is to set aircraft fees for the airport of Birmingham. The fee consists of a payment per movement and a contribution to capital cost of the runway facilities. The results showed that the existing fees were not efficient because there was subsidizing of small planes to large planes. In Engevall et al. (1998) a cost allocation problem is solved for a oil and gas company. The cost had to be divided among customers that are visited in a traveling sales problem. The cost allocation methods, Shapley, nucleolus and tau-value are compared to the values used by the oil and gas company. Sánchez-Soriano et al. (2002) describe a cost allocation problem for a transport system in Alicante, Spain. Frisk et al. (2010) apply the cost allocation concept to forest transportation in Sweden. Harvested logs are stored along the road or in storage terminals before they are transported to the sawing mill. The supply and demand of a company is scattered over the area. Forest transportation is categorized as high volume and long distance. Collaboration between companies can reduce the transportation cost. Based on the results an equal profit cost allocation rule was created. The results of the equal profit rule are the starting conditions for the negotiations between the companies.

1.3 Terminology

In 2030, the terminals in the Port of Rotterdam are expected to have specific functions in the distribution process of containers to the Hinterland. These functions are deep sea terminal, Barge/Rail terminal or empty depot. The deep sea terminal has facilities to handle big consolidated cargo flows to the Hinterland by truck, rail and barge. The barge and rail terminals will bundle small cargo flows for Hinterland destinations. The empty depots repair containers, do pre-voyage checks and store empty containers. Whether a cargo flow will be handled by the deep sea terminal or by the ITT system depends on the size of the cargo flow. Support activities are needed for a proper-functioning logistic chain of containers. These activities are cleaning and pre-voyage check of the containers, storage of empty containers, repair of damaged containers and inspection of container loads by customs. The support activities generate container transport that can be executed by the ITT system. Figure 3 shows the container flows and the role of ITT.

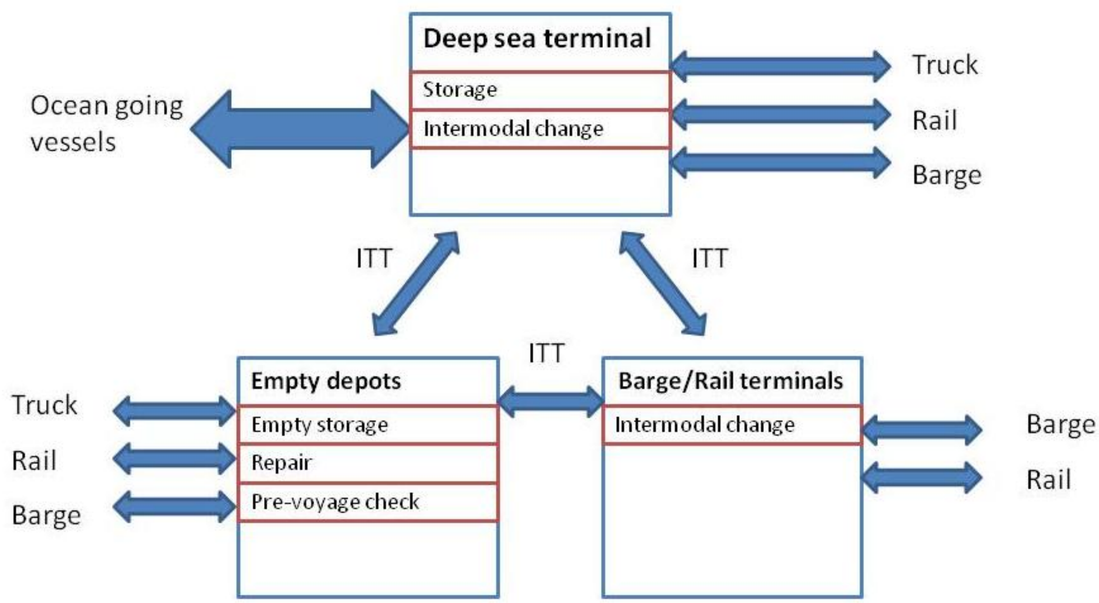

Figure 3: The role of ITT in the container distribution process

MV1 facilitates one Common Rail Terminal (Rail Terminal West) and one Common Barge Terminal (Barge Service Center Hartelhaven). MV2 will have a Common Rail Terminal and a

Common Barge Terminal. The geographical location of the terminals is represented in Figure 4. The participants and terminal names can be found in Table 1.

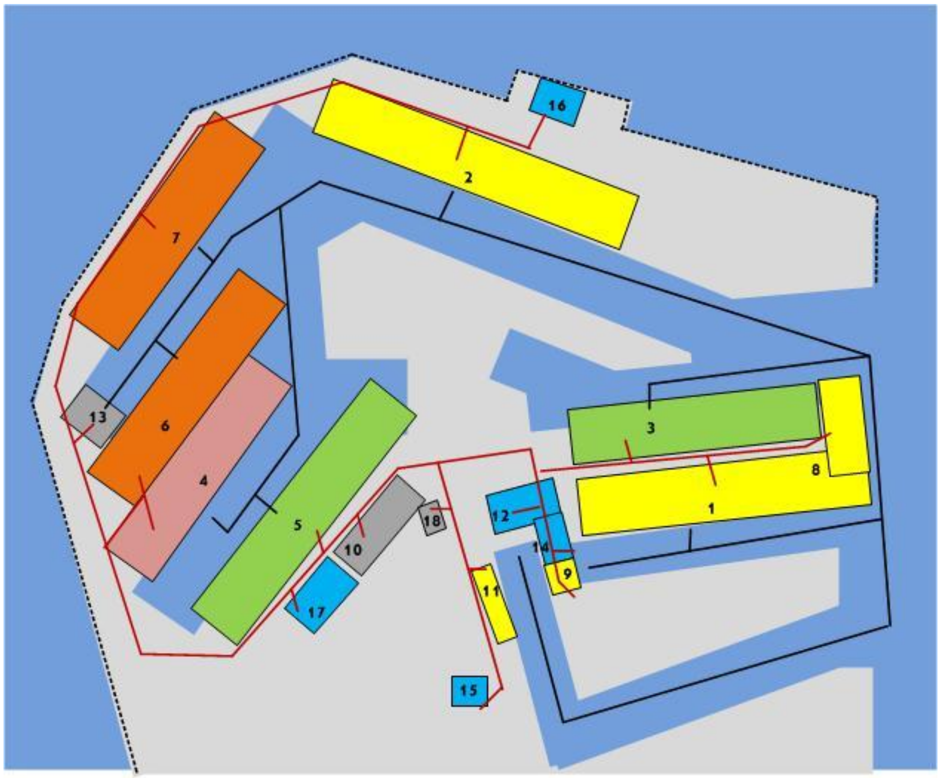

Figure 4: Participants at the Maasvlakte area

Table 1: Participants and the function in the container distribution process (Port of Rotterdam Authority, 2012a)

Player	Terminal	Name
1 ECT	1	ECT Delta Terminal
	2	Euromax Terminal
	8	ECT Delta Barge Feeder Terminal
	9	Delta Container Services
	11	Rail Terminal West
2 APM	3	APM MV1 Terminal
	5	APM MV2 Terminal
3 RWG	4	Rotterdam World Gateway
4 Kramer	12	Barge Service Center Hartelhaven
	14	Kramer Delta depot
	15	Van Doorn Container depot
	16	Empty depot MV1
	17	Empty depot MV2
5 Common services	10	Common Rail Terminal
	13	Common Barge Service Center
	18	Douane
6 Player 6	6	T3
	7	T4

A set of transport equipment for ITT transport is showed in Figure 5. The transport equipment can be divided into equipment that is allowed on public road (a, b and c), uses a private transportation network (d, g, h, and i), uses waterways (e) or the rail network (f). The most transport equipment can carry up to two TEU. Exceptions are the Multi Trailer Service (10 TEU), the Barge (50 TEU) and the Train (50 TEU). In the case of barges and trains, the capacity is large enough to justify a schedule based on a timetable. A train or barge will visit all terminals in a fixed order. If a container is not ready when the train or barge arrives, the container is scheduled for the next departure. Transport equipment with large capacity can be complemented with for example trucks to deliver containers with short delivery time.

(a) Truck and chassis (Truck)

(b) 3 TEU truck (3TT)

(c) Terminal Tractor and Chassis (TTC)

(d) Multi Trailer Service (MTS)

(e) Barge/ Inland shipping (Barge)

(f) Train

(g) Automated Guided Vehicle (AGV)

(h) Automated Guided Lift Vehicle (ALV)

(i) Magnet transportation lane (MTL)

Figure 5: Different transport equipment (Diekman and Koeman, 2010; Port of Rotterdam Authority, 2012d)

Chapter 2 Container demand scenarios

The demand of containers that will be transported by the ITT system in 2030 is uncertain. In this chapter, three scenarios will be constructed that describe the possible demand of containers. Based on the predictions of the Port Authority, the container flows sizes between the terminals are derived. The containers do not arrive equally over time. Based on data about the current container operations, the size of the peak factor will be determined. The size of the container flow together with the peak factor determine the capacity of the ITT system. Each scenario will be described by an Origin/Destination matrix and a peak factor. The demand scenarios are input for the ITT simulation model.

2.1 Yearly number of containers

The Port of Rotterdam Authority makes predictions about future container transport in the Port Vision 2030 (Port of Rotterdam Authority, 2011b). Based on the predictions, the total container transport is between 19 million TEU in a negative prediction and 31 million TEU in a positive prediction. The development of the Port of Rotterdam as a hub function for other ports in Europa is important for the ITT system. If the Port of Rotterdam becomes a container hub, many transhipment containers are handled in the port area. Larger vessel will stop only at a single terminal in the port area. Containers will be redistributed to other terminals before continuing the next leg of transportation. That will increase the demand for the ITT system.

The scenarios are based on the available handling capacity for ITT in the Port of Rotterdam. All available handling capacity in barge- and rail terminals and empty depots will be used for ITT. In scenario 2, 30% of the barge- and rail terminal and empty depot capacity is used commercially. The commercial use does not generate an ITT movement. When there will be no common barge terminal and common rail terminal, the demand will be according scenario 3. Furthermore the ITT container flows are unbalanced. The imbalance in container movements of the ITT systems is levelled by the normal container movements. The import of full containers exceeds the export of full containers. Empty containers are exported more.

Scenario 1: High demand scenario

The assumptions made for scenario 1 are summed up below. Table 2 shows the amount of containers transported by the ITT system in scenario 1. How the assumptions results in ITT containers flows is explained in Appendix 2: Construction of a scenario.

- The demand of ITT containers between deep sea terminals is taken as 1% of the transshipment containers from the Global Economy scenario of the Port of Rotterdam Authority. The 1% is based on the same assumption as used in the report of (Diekman and Koeman, 2010).
- Deep sea terminals have facilities for X-ray scanning, nuclear detection and physical inspection of containers available within the terminal area. Containers for second-line

scanning are transported to the central customs facility by the ITT system. Only 0.5% of all containers have to visit the central customs facility.

- The transportation of empty containers to and from empty depots can only be done by use of the ITT system.
- The capacity of the common barge and rail terminals is used completely. Every container handling move at common barge or rail terminal generates an ITT movement.
- The capacity of the rail terminals and barge terminals is restricted to 1.756 million and 0.935 million respectively.
- Of the containers that are transported by the ITT system, 35% are empty and 65% are full. Of the empty containers, 35% is import and 65% is export. Of the full containers, 60% is import and 40% is export.
- Empty depots have a capacity of 25,000 containers per hectare.
- 45% of the empty containers are transported by rail and 55% by barge.
- The new ITT system replaces the current ITT system with MTS service at the MV1.

Table 2: ITT container flows in scenario 1 (TEU/year)

To / From	Deep sea terminals	Barge Terminals	Rail Terminals	Customs	Empty depots
Deep sea terminals	94000	425865	628690	155000	266175
Barge terminals	283910	0	0	0	146396
Rail terminals	943035	0	0	0	119779
Customs	155000	0	0	0	0
Empty depots	494325	78829	64496	0	0

Scenario 2: Reduced demand

Scenario 2 (Table 3) takes the same assumptions as scenario 1 but differs at the following points:

- The total transshipment containers is equal to 8 million, which corresponds with the European scenario of the predictions of the Port of Rotterdam Authority (Port of Rotterdam Authority, 2011b).
- The demand for second-line scanning at the central customs facility is equal to 0.25% of all containers handled in the port.
- Commercial parties operate the empty depots at the MV area. Trucks can bring and pick up empty containers next to the ITT system. The number of ITT movements is not equal to the capacity of the empty depot, but equal to 70%. The other capacity will be transported by commercial trucks that do not make use of the ITT system.
- Commercial parties operate also the common barge and rail terminals. Transshipment of containers from short-sea to inland shipping uses handling capacity that cannot be used for ITT. Scenario 2 assumes that only 70% of the handling operations of the barge- and rail terminals generate an ITT movement.

- The import/export ratio is equal to 40%/60% for empty container and 55%/45% for full containers.
- The current ITT system with MTS service stays available.

Table 3: ITT container flows in scenario 2 (TEU/year)

From \ To	Deep sea terminals	Barge terminals	Rail terminals	Customs	Empty depots
Deep sea terminals	80000	260876	486801	75000	196560
Barge terminals	213444	0	0	0	108108
Rail terminals	594979	0	0	0	88452
Customs	75000	0	0	0	0
Empty depots	294840	72072	58968	0	0

Scenario 3: No common barge and rail terminal

Scenario 3 (Table 4) takes the same assumptions as scenario 1 and 2 but there will be no common barge and rail terminal at the MV2 area. Intermodal change for low frequent Hinterland connections will be done by the barge terminal and rail terminal at the MV1.

Table 4: ITT container flows in scenario 3 (TEU/year)

From \ To	Deep sea terminals	Barge terminals	Rail terminals	Customs	Empty depots
Deep sea terminals	80000	97251	219051	75000	196560
Barge terminals	79569	0	0	0	108108
Rail terminals	267729	0	0	0	88452
Customs	75000	0	0	0	0
Empty depots	294840	72072	58968	0	0

2.2 Container peak factor

The arrival and departure of containers at terminals is not equally distributed over time. The deep sea terminal tries to balance the water side operation. The landside operation of the deep sea terminal has more peaks due to limited operational hours of trucks and trains. In general it can be said that the first trucks arrive around 6 AM and the last trucks leave at 6 PM. Trains are scheduled from Monday afternoon until Saturday afternoon (Van Schuylenburg, 2013). Barges approach the terminal more or less constant over the day. For the design of the ITT system, it is important to know the average and peak flows. Designing the ITT system for average flows leads to under-capacity, while designing for peak flows leads to over-capacity.

Direct data about containers flows from the deep sea terminals is not available in this study. The deep sea terminal balances the arrival of containers at the water side of the terminal. To estimate the peak flows that will be handled by the ITT system, data about the container flows at the landside of the terminals is obtained. The peaks in the number of containers arriving in the ITT system can be caused by the capacity restrictions at the landside at the landside of the deep sea terminal. In the year 2030, the peaks are likely to flatten because trains will run 24 hours a day and the share of trucks will be reduced. Therefore, departure data is gathered about the number of trucks, trains and barges leaving the different terminals at the current Maasvlakte area. The available data about arrivals of trucks, trains and barges will be combined to construct a peak factor (Appendix 1).

Truck data

Direct data about truck arrivals at the gate of the deep sea terminals is not available in this study. But data is available about the number movements on the A15 highway heading towards the Maasvlakte area. The database of Regiolab Delft (Regiolab-Delft) holds data per minute from loop detectors of the A15 highway. The data describes the number of movements, the speed and the direction of the movement. The point of observation is close the Maasvlakte Area to exclude non-container carrying transport as much as possible. The intermodal split between trucks, trains and barges is used to scale the highway movements to truck movements. The average load per truck is assumed to be equal to the TEU factor of 1.7 (Port of Rotterdam Authority, 2012b).

Train data

Train data is obtained from Keyrail about the number of arriving and departing trains from the emplacement Maasvlakte West (Keyrail, 2013). The number of containers per train is gained from the Prorail handbook (ProRail, 2011). The average length of a train is 500, which are 25 railcars that can carry 3 TEU. The maximum number of TEU on a train is 105. An average train is loaded for 90%. Trains can be operated as ideal shuttle or start up shuttle. In ideal shuttle is loaded completely at the origin. A start up shuttle hops between several stops before the train is fully loaded. The assumption is made that due to the shuttle process the trains are loaded for 70% when leaving the Maasvlakte. The average number of TEU per train is equal to 47.

Barge data

Currently barges are handled at the three deep sea terminals (ECT Delta, APM MV1 and EuroMax). The number of arriving and departing barges is determined for each terminal (APM Terminals Rotterdam, 2013), (ECT, 2013). The average number of containers at a barge is based on the information from NextLogic (Nextlogic, 2013). A real life performance meeting identified that the average call size of a barge at a deep sea terminal is equal to 44 TEU.

Combined data

Hourly data about container movements of trucks, trains and barges is aggregated in Figure 6. Hinterland transport by truck is concentrated on weekdays. Trains are mainly scheduled from Monday afternoon to Saturday afternoon. Barges operate equally over the week. The number of containers transported is almost twice as high on weekdays than on weekend days. Figure 7 shows the number of containers at the landside of the deep sea terminals per hour for an average weekday. There is a peak in the morning and a slight peak in the afternoon. During the night the demand is much lower. In weekend days the number of containers are more balanced over the day as shown in Figure 8.

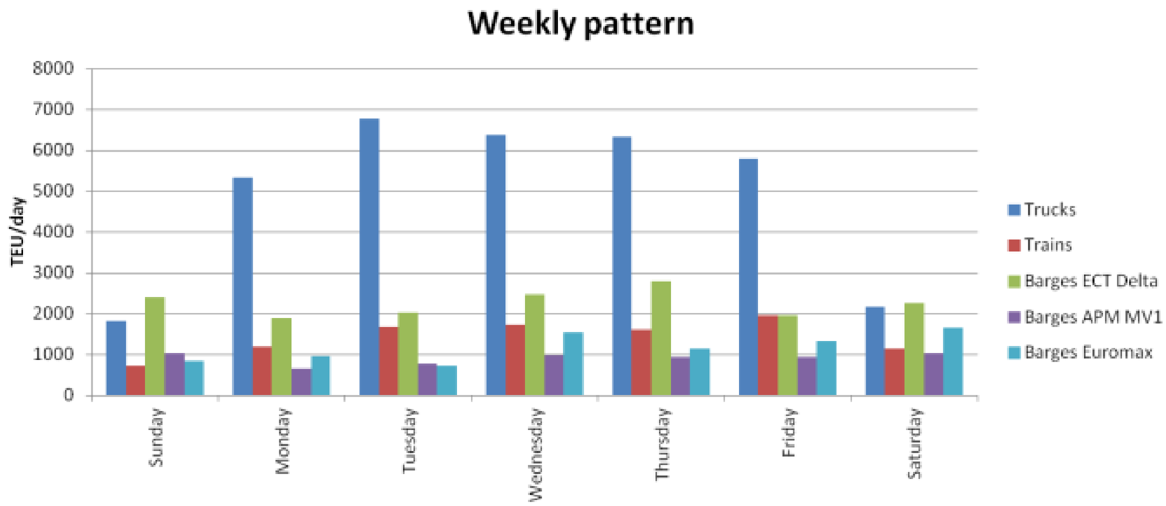

Figure 6: Containers per day per modality

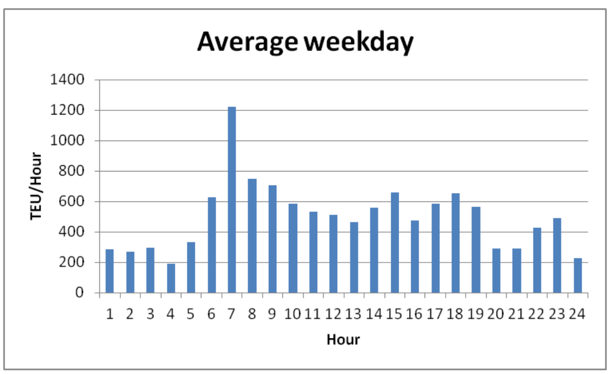

Figure 7: Demand per hour of the day for an average weekday

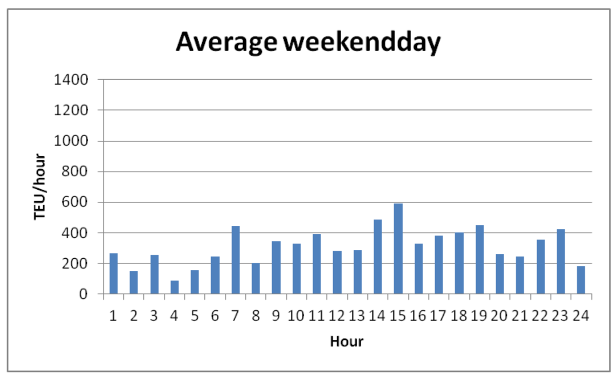

Figure 8: Demand per hour of the day for an average weekend day

The peak factor is determined by the average demand of containers per timeslot of three hours divided by the average demand of containers per day. A distinction will be made for weekdays and weekend days.

$$\text{Peak factor} = \left[\frac{\text{Average demand of containers per 3 hours}}{\text{Average demand of containers per day}}\right]_{\text{weekday,weekendday}}$$

The yearly number of containers and the peak factor will be combined in the container demand scenarios.

2.3 Container demand scenarios

The design of the ITT system for the year 2030 has many uncertainties. The throughput of containers of the ITT system is determined by economic developments. To deal with the uncertainty in demand of containers, three scenarios are created.

The three scenarios cover the extremes in demand for the ITT system. The chance of actual realization of the ITT system is higher when it has flexibility for different demands of containers. Also during the years before the final capacity is reached, the ITT system has to be competitive. Table 5 summarizes the yearly demand in containers for the different scenarios. The main causes of ITT transport is the transport between deep sea terminals and the common rail and barge facilities. The transport between empty depots and deep sea terminals are also significant container flows. The yearly number of containers are assigned to individual terminals based on the container flows as described in paragraph 2.1. In the Origin/Destination matrices of Appendix 2, the container flows are assigned to terminals based on the capacity of the terminal and the backdoor connections (Appendix 6).

Table 5: Total yearly ITT movements per scenario

	Total yearly movements in TEU
Scenario 1	3.34 million
Scenario 2	2.15 million
Scenario 3	1.42 million

Scenario 1 (Table 6) will have also the highest peak factors that coincidence with the current peak factors as found the data about trucks, trains and barges. A main cause of the peak factors are the operating hours of trucks and trains. In the future, the operating hours of trucks and trains will be more evenly spread over the day and therefore dampen the peak factors. No peak factors are assumed in scenario 3.

Table 6: Peak factors container arrival times

		0-3h	3-6h	6-9h	9-12h	12-15h	15-18h	18-21h	21-24h
Scenario 1	Weekday	0.57	0.77	1.79	1.09	1.12	1.14	0.76	0.76
	Weekend day	0.71	0.52	1.05	1.06	1.45	1.18	1.01	1.02
Scenario 2	Weekday	0.80	1.25	1.25	1.00	1.00	1.00	0.90	0.80
	Weekend day	0.90	0.90	1.00	1.10	1.10	1.10	1.00	0.90
Scenario 3	Weekday	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Weekend day	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Chapter 3 The ITT simulation model

This chapter describes the simulation model built to simulate the ITT system. The ITT simulation model accommodates different container demand scenarios, different transporters and different coalitions. The objective of the simulation model is to determine a number of transporters for a given input of containers, the total distance travelled by transporters, the drive time and the container throughput time.

3.1 Model description

In the ITT simulation model (Figure 9) containers are as entities. Container characteristics like the destination terminal and delivery time are assigned to each container. The container waits at the container queue of a terminal before picked up by one of the transporters. A transporter travels between the terminals and delivering containers. If a transporter enters a terminal, the time and kilometers driven are measured. The transporter experiences a delay because of entering the terminal property. First the loaded containers will be unloaded. The container throughput time and penalty time will be measured for each unloaded container. If the transporter has free capacity, it will load new containers. Transporters can only load containers if transporter belongs to the terminal owner or the terminal owner is part of the coalition for which the transporter drives. After the loading process, the container travels to the destination or when it is empty it will enter the transporter queue at the terminal. Empty transporters can be released again when there is a demand for transporters. The ITT system is modelled with Rockwell Arena Simulation V14.

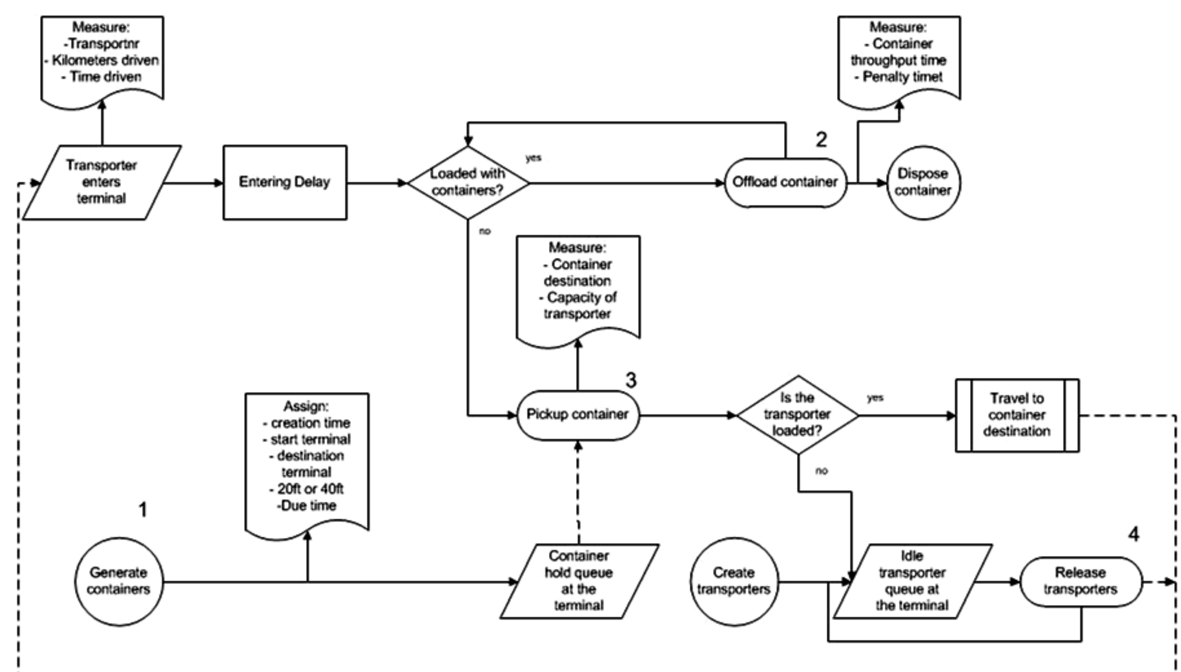

Figure 9: The ITT simulation model

Container generation (1)

The ITT simulation model creates an entity for every container that arrives in the ITT system. To simulate the arrival pattern of containers, the following formula is applied:

$$\mathrm{T_{arrival}} = 24 \cdot \mathrm{TEU\ Factor} \cdot \frac{1}{\mathrm{Peak\ factor\ (Hour, Day)}} \cdot \frac{1}{\mathrm{Day\ Load}} \cdot [\mathrm{T_{annual}}]_{\mathrm{terminal}}$$

$T_{arrival}$	= Arrival time between two containers in hours
TEU Factor	= The ratio between 20ft and 40ft containers
Peak factor (Hour,Day)	= The peak factor per hour and day from the container demand scenario. (See Table 6)
Day Load	= The arrival pattern that represents the arrival of containers over the days of the week (see Table 7)
T_{annual}	= Arrival time between containers based on the annual number of containers from the O/D matrix (See Appendix 3)

The container generation process will be explained by an example. The arrival time between two containers for Monday 09.00h till 12.00h for terminal 1 in the case of scenario 1 is:

$$\mathrm{T_{arrival}} = \mathrm{TEU\ Factor} \cdot \frac{1}{\mathrm{Peak\ factor(Hour, Day)}} \cdot \frac{1}{\mathrm{Day\ Load}} \cdot 24 \cdot [\mathrm{T_{annual}}]_{\mathrm{terminal}}$$
$$= 1.7 \cdot \frac{1}{1.79} \cdot \frac{1}{0.16} \cdot 24 \cdot 0.000173$$
$$= 1.7 \cdot 0.558 \cdot 6.25 \cdot 24 \cdot 0.000173 = 0.0246\ \mathrm{hour}$$

Because Monday is a weekday, the day load factor is 0.16. The peak factor for Monday between 09.00h and 12.00h obtained from Table 6 is equal to 1.79. For scenario 1, the annual number of containers departing from terminal 1 is 300,502. This results in a T_{annual} time for terminal one of 0.000173. In the simulation, the $T_{arrival}$ time is input for an exponential distribution. The exponential simulates the randomness of arrival of containers within the 3 hour time interval.

In the generation process, each containers gets an attribute with the start terminal and creation time of the container. Furthermore, the size of the container is randomly assigned where 30% of the containers is 20ft and 70% of the containers is 40ft. Based on the Origin/Destination matrix of the container demand scenario, a discrete probability function is created. As example, the cumulative discrete probability function for terminal 1 in scenario 1 is given in Appendix 5. The simulation assigns randomly a destination to the container based on the discrete probability function of the specific terminal. The due date of the container is drawn randomly from an Erlang K distribution. The shape of the Erlang K distribution is given by an integer number. For the k factor is the value of 5 taken as proposed by the PoR authority (Van Schuylenburg, 2013). The mean of the distribution is equal to 6 hours (Trail Onderzoekschool, 1996). The due date of the container is the current time of the simulation plus the time obtained from the Erlang K distribution. (see Appendix 4)

Unloading process (2)

After entering the terminal, the transporter is unloaded first. Figure 10 shows the unload process of the ITT simulation model. The unload process checks how many containers are loaded on the transporter. In the search process only containers with the terminal as destination will be selected. The capacity of the transporter becomes free and the container will be unloaded. A delay process simulates the offloading of the container. The unloading process starts over again until the transporter is empty or there are no containers to unload for this terminal. The transporter is ready to pick up new containers.

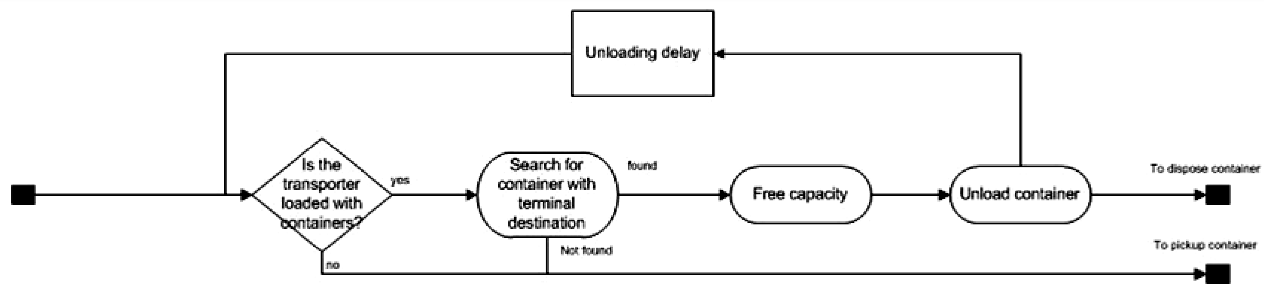

Figure 10: The unload process

Loading process (3)

The loading process follows after the unloading process. Only transporters that are owned by the terminal are allowed to load containers. If the owner of the terminal is in the coalition, then transporters are also allowed to load containers. Figure 11 shows the loading process.

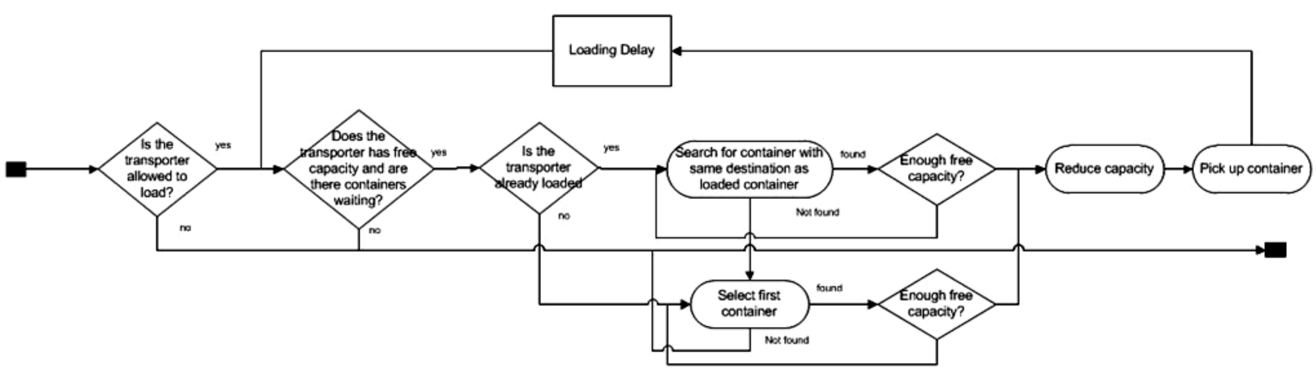

Figure 11: The loading process

At the start of the loading process, the transporter checks if the transporter has free capacity to load containers. The process checks also if there are containers waiting to be loaded. If both conditions are fulfilled, the loading process continues to check if there are already containers loaded on the transporter. If the transporters carries already a container, a container with the same destination is loaded otherwise the first container in the container queue is selected. By loading containers with the same destinations, the number of empty kilometers driven by the transporter is reduced. When the capacity of the transporter is not exceeded, the container is loaded and a loading delay occurs. The loading process continues until the transporters has no capacity anymore or there are no containers waiting in the queue. The container waiting queue is sorted on due time. Containers with a short due time will be loaded before containers with a longer due time.

Dispatching rules

In abundance of an overall planning system for the transporters, dispatching rules are used to determine the pick-up of a new load. The first loaded container determines the destination for the truck and the AGV. The MTS has a fixed route visiting each terminal. A terminals is only skipped when the MTS cannot load containers at the terminal and carries no container with destination of that terminal. Only when no containers are loaded, the transporter enters the idle transporter queue.

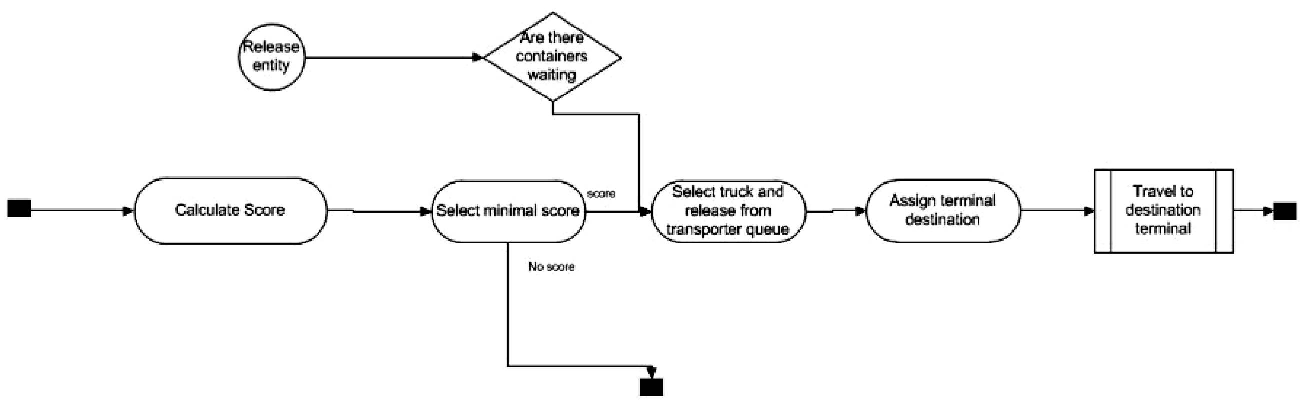

Figure 12: Dispatching of empty transporters

A dispatching rule can be single attribute or multi-attribute. A single attribute dispatching rule assigns empty vehicles based on a single parameter, for example the longest waiting time for a container in the system. Multi-attribute dispatching rules include more parameters. Different dispatching rules are compared on average waiting time, vehicle utilization and maximum waiting time (Le-Anh and De Koster, 2005). The multi-attribute dispatching rules give better results in a high load system than single attribute dispatching rules. A multi-attribute dispatching rule is applied in the ITT simulation model.

Figure 12 shows the dispatching of empty transporters. In the dispatching rule, a new terminal is assigned to empty transporters. The dispatching rule balances the transporters over different transportation jobs at the terminals. Due to the peak factor in the container demand, the required number of transporters differs over time. The ITT simulation model checks every five minutes for containers in the waiting queues or idle transporters. In that case, idle transporters will be released. Because there is a time delay between the assigning of a container and the actual pick-up of the container, the dispatching rule should send transporters to terminals with many containers in the waiting queue. The dispatching rule takes the due time of containers into account. Furthermore, the number of empty kilometers driven are minimized by selecting a nearby idle transporter.

The multi-attributed dispatching rule that is used includes:

- the number of waiting containers at a terminal;
- the due time of the first container waiting in the queue at a terminal;
- the distance to a terminal.

The dispatching rule calculates a score for each terminal:

$$\mathrm{Score_i} = \mathrm{f_1} \cdot (1 - \mathrm{N_{wait,i}}/\mathrm{N_{maxwait}}) + \mathrm{f_2} \ \cdot (\mathrm{T_{due,i}}/\mathrm{T_{maxdue}}) + \mathrm{f_3} \cdot (\mathrm{D_i}/\mathrm{D_{max}})$$

And selects the terminal that has the minimum:

$$\mathrm{minScore} = \min_{\mathrm{i=1 \dots n}} (\mathrm{Score_i})$$

Where,

minScore	=	Minimum score of all terminals
$N_{wait,i}$	=	Number of containers waiting at terminal i
$N_{maxwait}$	=	Maximum number of containers waiting for all terminals
$T_{due,i}$	=	The due time minus the current time of the first container in the queue at terminal i
T_{maxdue}	=	The maximum due time minus the current time of the first container in the queue for all terminals
D_i	=	Distance from the current terminal of the transporter to terminal i
D_{max}	=	Maximum distance from current terminal to any terminal
f_1	=	Weight factor for the number of waiting containers at the terminal
f_2	=	Weight factor for the shortest delivery time
f_3	=	Weight factor for the shortest distance

The score is calculated for every terminal separately. The transporter will be send to the terminal with the lowest score. The weight factors in the dispatching rule can steer towards a good allocation of free transporters to terminal. Based on initial experiments, applying the weights of [0.4 0.2 0.4] for [f1 f2 f3] give good results.

3.2 Input parameters

The simulation of the ITT system is a non-terminating system. In the start situation, the vehicles are spread equally over all terminals. A warm-up period of 24 hours is applied so that the system is filled with containers and the transporters are distributed over the different terminals. No statistics are collected during the warm-up period. The simulation runs for 192 hours including the warm-up period. This corresponds with a simulation time of one week. Transporters are available for 24h a day and do not have breakdowns. Furthermore, the simulation assumes that there is an unlimited waiting queue at the terminal side. The loading and unloading process takes on average 2 minutes corresponding with a crane with a capacity of 30 moves per hour. Table 7 shows the input parameters for the ITT simulation.

Table 7: Input parameters for the ITT simulation

Parameter	Value	Parameter	Value
TEU Factor	1.7[a]	Day load weekend day	0.10
Peak factors	Table 6	Enter delay truck [hour]	0.0166
Origin/Destination matrices	Appendix 2	Load time [hour]	0.0333[b]
Day load weekday	0.16	Standard deviation load time [hour]	0.01

[a] (Port of Rotterdam Authority, 2012b)

[b] (Port of Rotterdam Authority et al., 2002)

The distance between the terminals is according Figure 13. The ITT simulation divides the road into zones of 50 meter. Only one transporter is allowed per zone.

Figure 13: Distances of the ITT system (Port of Rotterdam Authority 2012c)

The transporters modelled in the ITT simulation are given in Table 8.

Table 8: Transportation scenarios

Transporter	Capacity [TEU]	Manned	Average speed[km/h]
Truck	2	Yes	40
MTS	10	Yes	30
AGV	2	No	40

Chapter 4 The cost function

The previous chapter described the simulation model built to analyse an ITT configuration for a given input scenario. To compare different ITT configurations economically, the cost per ITT configuration will be calculated. This chapter describes the cost function to calculate the cost of the ITT system. The cost function is constructed in a way that different ITT configuration can be analysed as well as different coalitions of participants. The cost function uses input from the simulation runs. The cost of the ITT system, calculated with the cost function, is input for the game theory analysis of chapter 5. This chapter describes the method to derive to the cost function, the inputs of the cost function and an example how to calculate the cost of the ITT system with the cost function.

Assumed is a neutral party that provides the ITT system. Each player can individually decide to join or not to join the ITT system. The neutral party provides the ITT system based on one of the ITT configurations. If a participant does not join the ITT system, the participant will buy trucks to deliver the containers. The terminal that sends the container pays for the transportation.

The cost function will be used to compare different ITT configuration with each other, therefore the cost function is specific for each type of transporter used. The cost of a transporter consists of fixed cost and variable cost. The fixed costs include the cost for depreciation, interest and a fixed percentage of maintenance. The variable costs are the fuel cost related to the distance travelled with the transporters and the wage cost of the driver. One of the performance measures of the ITT system is the number of containers that arrive in time at the final destination. The cost function will penalize for late containers. The cost for lifting a container on the transporter is not included. Those costs will be paid by each player individually and do not affect the transportation cost of the ITT system. The ITT system provided for the coalition set will be calculated on the following formula:

$$\mathrm{YC_i} = \mathrm{n_t} \cdot \mathrm{fixcost_c} + \mathrm{hours_{driver}} \cdot \mathrm{wage} + \mathrm{d_{km}} \cdot \mathrm{fuel_{cost}} + \mathrm{penalty\ cost} \cdot \mathrm{t_{late}}$$

Where,

$\mathrm{YC_i}$	= Yearly total cost for coalitionset or player i	[€]
$\mathrm{n_t}$	= Number of transporters	[-]
$\mathrm{fixcost_c}$	= fixed cost of transporter type c	[€]
$\mathrm{hours_{driver}}$	= number of hours driven by drivers	[hour]
wage	= wage cost of a driver	[€/hour]
$\mathrm{d_{km}}$	= distance in kilometer	[kilometer]

$\text{fuel}_{\text{cost}}$	= Fuel cost per kilometer	[€/km]
penalty cost	= Cost for lateness of containers	[€/hour]
t_{late}	= Total hours of late containers	[hour]

The yearly cost of the coalition set consists of four components. The first component is the fixed cost of the transporter multiplied by the number of transporters that is used for a coalition. The cost related to a driver is only included when a transporter requires a driver. The number of driving hours, obtained from the simulation results, is multiplied by the wage of the driver. Furthermore, the fuel cost is calculated based on the number of kilometers driven. The simulation model measures the time between the assigned arrival time and the actual arrival time. When the actual arrival time of a container exceeds the assigned arrival time, a penalty cost is included. The cost parameters are based on the work of (Diekman and Koeman, 2010). Table 9 shows the cost parameters of the ITT system. For more detail refer to Appendix 8.

Table 9: Cost parameters for the ITT system (Diekman and Koeman, 2010)

	Fixcost [€]	Wage [€/hour]	Fuel cost [€/km]	Penalty cost [€/hour]
Truck	€42,783	25	0.25	15
MTS	€73,500	25	0.375	15
AGV	€74,000	-	0.25	15

The behaviour of coalitions of the ITT players is of interest. The cost of a coalition is based on the players in the coalition. This results in a cost function that is player specific. The cost of a coalition can be calculated with the following formula:

$$\text{Cost}_{\text{coalition}} = \text{YC}_{\text{S}} + \sum_{\text{S}}^{\text{N}} \text{YC}_{\text{i}}$$

Where,

$\text{Cost}_{\text{coalition}}$	= The yearly cost for all players in the Port of Rotterdam for ITT transportation
YC_{S}	= The yearly cost of the cooperative ITT transport by the coalition set
YC_{i}	= The yearly cost of an individual participant
S	= The number of players in the coalition set
N	= The total number of players

With six players, there are 64 possible combinations to form a coalition set. The simulation runs provide the input to calculate the cost of the coalition set. The cost of the individual players is calculated based on the number of kilometers driven and the price per kilometers based on the commercial truck tariff. An example will be provided to show how the total cost for a coalition can be calculated with the cost function.

Example of calculating the cost of a coalition

In this example the coalition set consists of the players 1,3 and 6 given a demand according to scenario 1. The individual players are the players 2, 4 and 5. The cost of the ITT transportation of the coalition set is calculated together. The coalition set uses AGV's to as transporter.

Therefore it is not possible to calculate the individual cost. Based on the cost function introduced for the ITT system above, the total cost can be calculated for the coalition set {1,3,6}. The results from the simulation show that 49 trucks need 12.5 million kilometer to transport the containers. The total driving hours are 362648 and total hours of late containers are 1305 hours per year. Applying the formula:

$$\begin{aligned} YC_i &= n_t \cdot fixcost_c + hours_{driver} \cdot wage + d_{km} \cdot fuel_{cost} + penalty\ cost \cdot t_{late} \\ &= 49 \cdot 42782 + 362648 \cdot 0 + 12.5 \cdot 10^6 \cdot 0.25 + 15 \cdot 4524 = € \ 6.756 \text{ million} \end{aligned}$$

Both the cost for the individual players is known and the cost of the coalition set. The cost for the coalition with coalition set {1,3,6} is then:

$$\begin{aligned} Cost_{coalition} &= YC_S + \sum_{S}^{N} C_{km} \cdot d_{km} \\ &= 6.756 + 2.048 + 6.651 + 5.032 = € \ 20.490 \text{ million} \end{aligned}$$

Table 10: Yearly cost for ITT transport for coalition set {1,3,6} in the case of AGV

	n_t	$fixcost_c$	$hours_{driver}$	Wage	d_{km}	$fuel_{cost}$	Penalty cost	t_{late}	Total cost
	[-]	[€]	[hour]	[€/hour]	[10^6 km]	[€/km]	[€/hour]	[hour]	[€]
Coalition set {1,3,6}	49	74,000	362648	0	12.5	0.25	15	4524	6,756,475
Player 2	12	42,783	46332	25	1.49	0.25	15	312	2,048,847
Player 4	25	42,783	166140	25	5.60	0.25	15	1924	6,651,987
Player 5	23	42,783	119912	25	3.98	0.25	15	3640	5,032,710
						Total cost			20,490,019

An overview of the cost per individual player can be found in Table 10. With the help of the cost function, different ITT configurations and coalition of players can be compared to each other. In the next chapter, the cost function will be applied to the simulation results of different ITT configurations.

Chapter 5 Results

In this chapter, the results of the simulation will be presented for the three container demand scenarios and the different transportation options. The performance of the ITT system will be described by the required number of transporters, the average and maximum container throughput time and the lateness of containers. The total cost of the ITT system will be calculated with the cost function of the previous chapter. Based on the concepts from game theory, the cost savings are divided over the 6 players. The benefit allocation and the achieved cost savings give insight in the value of a player for the ITT system.

5.1 Number of transporters

One of the main questions is the number of transporters that are required. The number of transporters needed depends on the type of transporter and the container demand scenario. The speed and the capacity of the transporter determine mainly the container throughput time. The container throughput time is the total time that a container is in the ITT system and consists of waiting time, transportation time, loading and offloading time. By applying more transporters in the ITT system, the waiting time of a container decreases, because the container will be picked up earlier from the stack. On the other hand, extra transporters are more expensive and increase the number of empty rides in the ITT system, because of the dispatching rule. The MTS has more capacity than the truck and the AGV and transports multiple containers at the same time. The containers loaded on the MTS will have longer travel time, because the MTS has a fixed route and will not travel directly to the destination of the container like the truck and AGV.

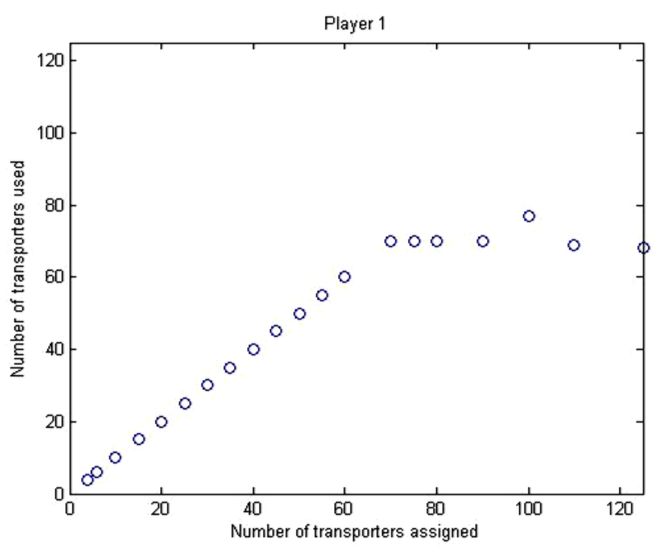

Figure 14: Number of trucks assigned versus used

Figure 14 shows the number of trucks assigned to player 1 and the number of trucks used. The simulation tries to reduce the number of trucks used for transportation. Only when more than

25 trucks are assigned, there is a balance between containers entered and disposed from the simulation. Increasing the number of transporters reduces the number of containers that arrive too late. The graph shows that adding more than 70 trucks, the simulation does not assign containers to those trucks. The assigned number of transporters should be between 25, the point that all containers will be delivered and 70, the maximum number of transporters used. The average throughput time of containers decreases when more transporters are assigned to the simulation. Figure 15 shows the average and maximum throughput time of a container in the ITT system for player 1. The simulation sorts the containers on due time in the queue of the terminal. Containers with a long due time will wait longer in the queue of the terminal to be picked up. When applying more transporters, the average container throughput time stabilizes around 2.5 hours for a truck. The maximum throughput time stabilizes around 20 hours. Figure 15 shows that adding more trucks to the simulation will not decrease the maximum throughput time of the containers. The dispatching rule for transporters does not steer upon container throughput time but aims to reduce the number of late containers. Lateness is an important criteria, because containers have to arrive in time at the destination terminal for further transportation by barge, train or deep sea vessel.

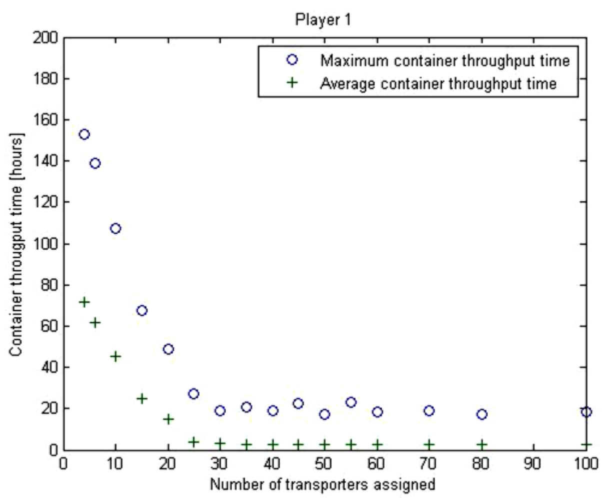

Figure 15: Container throughput times depending on the number of transporters (Truck, Scenario 1)

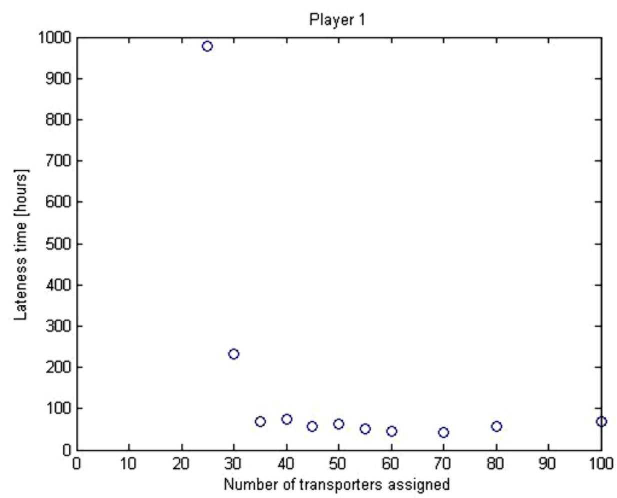

Figure 16: Lateness time versus number of transporters assigned (Truck, Scenario 1)

Figure 16 shows the total lateness of containers. The time that a container arrives later than the assigned arrival time will be added to the total lateness. The lateness of containers is not completely preventable. The due time distribution (Appendix 4) assigns due times, where the difference with the simulation time is close to zero. Those containers are already too late when they enter the ITT system. Therefore, adding more transporters will not eliminate completely the lateness of containers. Increasing the number of containers will reduce the lateness of containers. The total time of late containers for player 1 (ECT) is around 60 hours for around 12000 containers per week. The results for other players can be found in Appendix 7.

Table 11 shows the waiting times for containers in the queue at the terminals for player 1. The waiting times at terminal 8 and 9 are higher than at the other terminals. The dispatching rule of trucks causes the longer waiting time. Every time a truck is idle, a score is calculated at which terminal the truck has to pick up a new load. One argument is the number of containers waiting in the queue. The terminals 8 and 9 have a low demand of containers compared to the other terminals; therefore the number of containers waiting in the queue is lower. The dispatching rule does not assign transporters to terminal 8 and 9 equally as to the other terminals and therefore the average waiting time is higher. But the maximum waiting time is in the same range as the other terminals. When a container at terminal 8 or 9 is the longest waiting container, the dispatching rule gives priority to pick up that container first.

Table 11: Container waiting times at the terminal in hours

	Average waiting time [hour]	Maximum Waiting time [hour]
Terminal 1 queue	0.83	13.38
Terminal 11 queue	0.50	21.88
Terminal 2 queue	1.01	13.15
Terminal 8 queue	3.59	15.30
Terminal 9 queue	5.64	23.51
Total:	0.80	23.51

5.2 Cost per ITT configuration

Four cases are distinguished to calculate the total yearly cost. These cases are every player individual with trucks (Individual), combined transportation with trucks (Truck), combined transportation with AGV's (AGV) and combined transportation with MTS's (MTS). For every case, the container demand is taken according to the three scenarios as defined in Chapter 2. To calculate the total cost per ITT configuration, a three step process is required. The first step determines the number of transporters needed, obtained via the simulation model. The second step requires the results from the ITT simulation based on the number of transporters determined in the first step. Finally, the cost function (Chapter 4) is applied to determine the yearly cost.

Table 12: Number of transporters per ITT configuration

	Truck/AGV			MTS		
Scenario	1	2	3	1	2	3
Player 1	30	18	14	25	18	12
Player 2	12	6	4	5	4	3
Player 3	8	4	3	4	3	2
Player 4	25	17	14	18	10	10
Player 5	23	16	1	15	10	1
Player 6	11	7	4	7	5	3
Total:	109	68	40	74	50	31

In the case of individual transportation, the number of transporters assigned to a player is the point where the maximum throughput time stabilizes. Replicating the same procedure for each player, the total number of transporters can be obtained for each individual player. Multiple simulation runs are done to determine the number of transporters required for each player (Table 12). For the results of other scenarios refer to Appendix 7.

For the cases of combined transportation, the number of transporters required is based on the average container throughput time. In the case of truck and AGV, the average container throughput time is 3 hours and for the MTS it is 4 hours. Table 13 shows the number of vehicle required for truck, AGV and MTS for the different scenarios.

Table 13: Cost per ITT configuration

	Scenario	Number of transporters	Avg. throughput time [hours]	Total yearly cost [€]	Cost per TEU
Individual	1	109	2.69	26.5 million	€ 7.93
	2	68	2.64	17.5 million	€ 8.14
	3	40	2.95	10.9 million	€ 7.68
Truck	1	70	2.97	21.5 million	€ 6.43
	2	41	2.98	12.9 million	€ 6,00
	3	27	2.95	8.7 million	€ 6.12
AGV	1	70	2.97	9.5 million	€ 2.84
	2	41	2.98	6.0 million	€ 2.79
	3	27	2.95	3.9 million	€ 2.74
MTS	1	60	3.99	21.2 million	€ 6.34
	2	36	3.98	13.8 million	€ 6.41
	3	24	3.95	9.4 million	€ 6.62

When the ITT transportation is executed in a collaborative way, the number of transporters reduces compared to the individual transportation. There are synergy benefits like a reduction of empty rides and spreading of the peak in demand, resulting in a reduction of 39 (Truck and AGV) or 49 (MTS) transporters for scenario 1 (Table 13). Performing ITT in a collaborative way results in a reduction of transporters compared to individual transportation of 32% to 47%. The lowest reduction of 32% is reached at Scenario 3 between Truck (and AGV) and individual transportation. The highest reduction of 47% can be achieved in Scenario 2 with MTS compared to individual transportation. The percentage of empty kilometers is 45% for individual transportation while this reduces to 18% in the case of a shared pool of trucks. In collaborative transportation, the MTS requires the least amount of transporters, but has a higher container carrying capacity. The container carrying capacity of the MTS is not completely used because of the dispatching rule (Paragraph 3.1) in the simulation model. The MTS has a fixed route along all the terminals, while the truck and AGV find the shortest route depending on the carrying load.

Figure 17 and Table 13 show the cost comparison between different ITT configurations given a container demand scenario. Looking from the perspective of the port, the cost of individual transportation is in each container demand scenario higher than an ITT configuration that works collaboratively. Depending on the container demand scenario, a shared pool of trucks reduces the total yearly cost between 19% and 27%. A shared AGV configuration will reduce the cost with 64% to 66% and a MTS configuration between 14% and 21%.

Comparing the different collaborative ITT configurations, an ITT system performed by a pool of trucks is the most expensive solution. The cheapest solution is the use of AGV's. The fixed cost for AGV's is higher, but the cost reduction is achieved by eliminating the wage cost. The wage cost of the driver is a large proportion of the total cost. The cost function does not address the cost of handling a container from the transporter or the cost of infrastructure. The fixed cost of MTS is higher compared to the truck, due to the investment cost. However, the fuel cost and wage cost are less. The MTS can share the cost of the driver over multiple containers. The use of MTS will lead to higher container throughput times. A significant share of the cost of the MTS solution is the penalty cost. Optimized planning and scheduling can reduce the penalty cost. Table 13 shows that for the truck and the AGV, the cost per TEU increases when the demand increases. The peak factor in the demand causes a reduction in utilization. The MTS has spare capacity to dampen the peak and therefore the cost per TEU decreases with increasing demand.

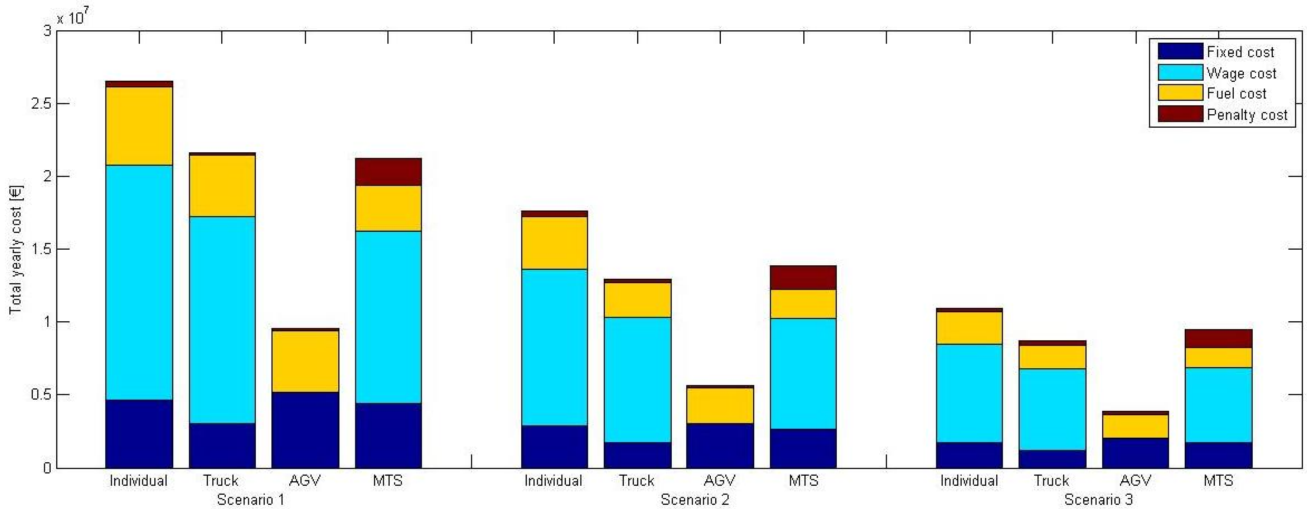

Figure 17: Cost per ITT configuration per scenario

5.3 Game theory applied on the ITT system

In this consecutive step, the cost savings of a coalition will be assigned to individual players based on game theory (Miras Calvo, 2008). Two approaches are followed. In the first approach, the number of transporters assigned to each coalition is the sum of the transporters assigned to each player individually. In the second approach, the exact required number of transporters for each coalition is determined. The cost of each coalition is calculated. Based on the results of all coalitions, a pay off vector is created where the payoff is the difference in cost between a coalition and individual case. The objective is to find the contribution of a player to the coalition.

In the first approach, the number of transporters assigned to a simulation run is determined by the moment where the maximum container throughput time stabilizes. Appendix 7 shows the simulation runs to determine the point where the maximum container throughput time stabilizes. Although the maximum container throughput time does not stabilize around the same value, the shape of the graph is always the same. Table 12 shows the number of transporters in a simulation run for each player.

Figure 18 shows the total yearly cost for all possible coalitions for AGV and MTS. Which players are represented in a coalition set can be found in Appendix 9. Applying the number of transporters from Table 12, to the ITT simulation model, there are no cost savings for the truck (Figure 18). The ITT configuration of AGV's and MTS show cost savings. Super additive, monotonic, convexity and essential (Table 14) explain the behaviour of the set of coalitions (See also paragraph 1.2). The tau-value and the Shapley value are both methods to create a "fair" cost allocation. The Core checks if the cost allocations hold individual rationality.

Table 14: Game characteristics

	Scenario	Super additive	Monotonic	Convex	Essential
AGV	1	No, {1} and {2}	No, {1,2,4} and {1,2,3,4}	No, {1} and {2}	No
	2	No, {1} and {2,5}	Yes	No, {1} and {2,5}	No
	3	No, {1} and {2,3}	Yes	No, {1} and {2,3}	No
MTS	1	No, {1} and {3}	No, {2} and {2,3,4}	No, {1} and {3}	Yes
	2	No, {1} and {2}	No, {1} and {1,2}	No, {1} and {2}	No
	3	No, {1} and {2}	No, {1} and {1,2}	No, {1} and {2}	Yes

The Core of the games is empty. The tau-value cannot be calculated because of the empty Core. This means that there is no cost allocation that holds individual rationality. However, the Shapley value can be calculated to find a cost allocation. Table 15 shows the Shapley value.

Table 15: The Shapley value (million €)

		Player						
	Scenario	1	2	3	4	5	6	Totals
AGV	1	4.42	0.56	0.33	3.07	2.14	1.08	11.60
	2	2.95	0.50	0.30	2.18	1.42	0.71	8.06
	3	2.25	0.29	0.16	2.05	0.06	0.56	5.37
MTS	1	1.64	0.24	0.37	0.81	0.19	0.63	3.88
	2	0.05	-0.05	-0.08	1.05	0.48	0.15	1.60
	3	1.93	-1.18	0.04	5.17	-0.58	-1.18	4.20

The Shapley value divides the cost savings to the individual players. According to the Shapley value, the most cost savings (4.42 million) should be assigned to player 1, followed by player 4 (3.07 million) and player 5 (2.14 million). In the AGV scenarios, the player with the highest assigned cost savings is player 1. The influence of player 5 on the cost savings decreases from scenario 1 to scenario 3. Because in scenario 1, the common rail terminal and common barge terminal are responsible for a large proportion of the container transportation.

The major drawback of this approach is that the synergy in a coalition is cancelled by applying too many transporters. The ITT simulation is not able to sufficiently reduce the number of

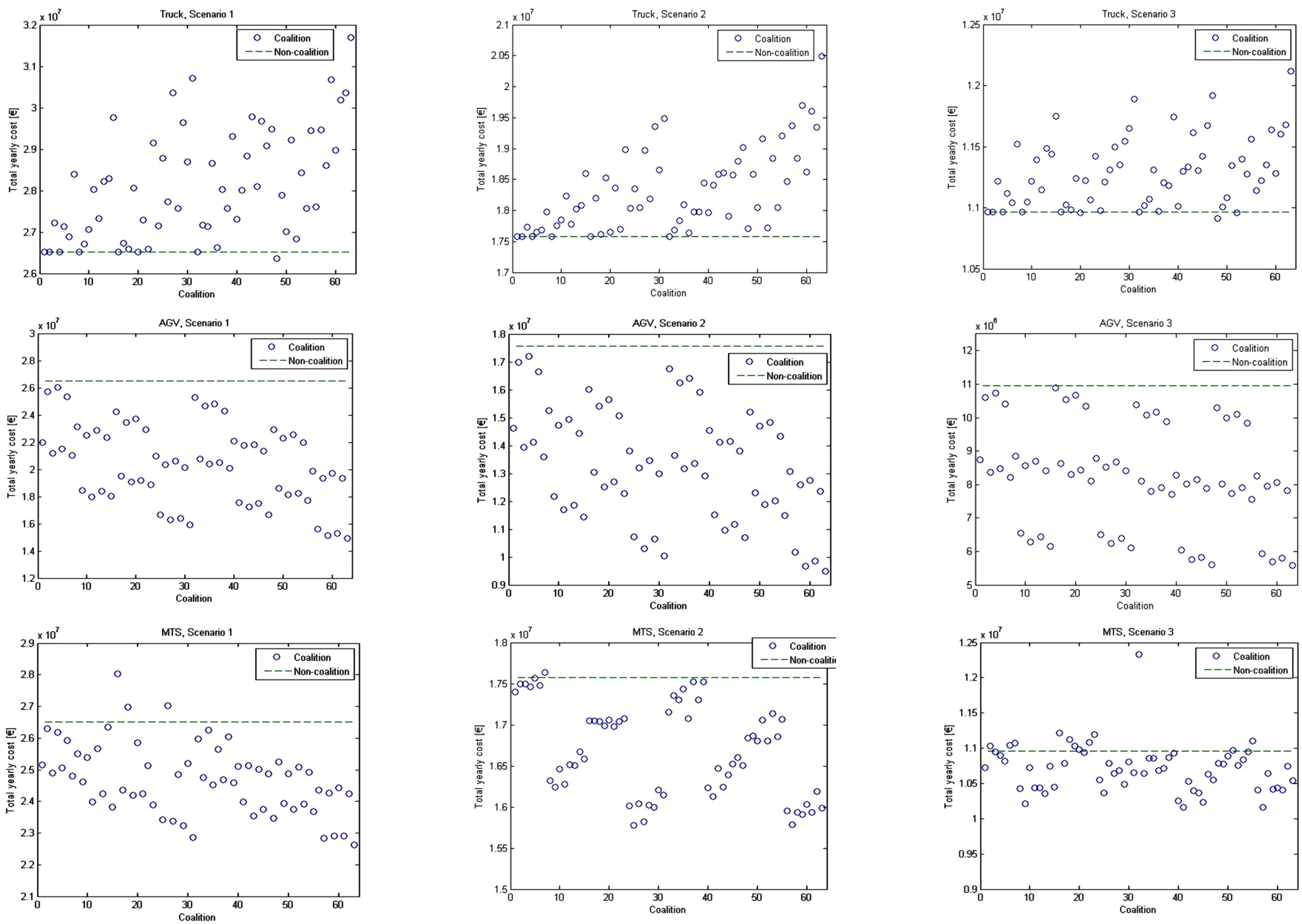

Figure 18: The results per coalition for truck, AGV and MTS

transporters to perform the ITT transportation efficiently. Therefore, the exact number of transporters should be determined before applying the cost function. This method is followed in the second approach.

In the second approach, the number of transporters is determined for each coalition. In every coalition is the number of transporters is reduced until the average throughput time is equal to 2.8 hours for truck and AGV and 3.8 hours for MTS. Table 16 shows the number of transporters assigned to each simulation run for scenario 1 of the truck and the AGV, Table 17 for MTS in scenario 1.

Table 16: Number of transporters assigned in reduced transporter scenario (truck, AGV)

{Coalition number}		Number of transporters											
{1}	30	{10}	31	{19}	52	{28}	45	{37}	41	{46}	45	{55}	61
{2}	12	{11}	55	{20}	23	{29}	67	{38}	23	{47}	67	{56}	49
{3}	37	{12}	27	{21}	50	{30}	49	{39}	48	{48}	28	{57}	71
{4}	8	{13}	53	{22}	33	{31}	72	{40}	30	{49}	51	{58}	55
{5}	33	{14}	35	{23}	58	{32}	11	{41}	55	{50}	33	{59}	75
{6}	13	{15}	59	{24}	42	{33}	37	{42}	36	{51}	57	{60}	51
{7}	39	{16}	23	{25}	66	{34}	17	{43}	60	{52}	32	{61}	73
{8}	25	{17}	46	{26}	48	{35}	43	{44}	35	{53}	52	{62}	57
{9}	47	{18}	28	{27}	70	{36}	16	{45}	60	{54}	38	{63}	70

Table 17: Number of transporters assigned in reduced transporter scenario (MTS)

{Coalition number}		Number of transporters											
{1}	25	{10}	23	{19}	41	{28}	36	{37}	33	{46}	32	{55}	47
{2}	6	{11}	44	{20}	20	{29}	57	{38}	17	{47}	54	{56}	37
{3}	28	{12}	21	{21}	40	{30}	41	{39}	39	{48}	21	{57}	57
{4}	5	{13}	43	{22}	22	{31}	61	{40}	21	{49}	41	{58}	42
{5}	27	{14}	27	{23}	43	{32}	10	{41}	45	{50}	25	{59}	62
{6}	9	{15}	47	{24}	37	{33}	29	{42}	27	{51}	45	{60}	41
{7}	31	{16}	20	{25}	56	{34}	13	{43}	51	{52}	24	{61}	61
{8}	18	{17}	39	{26}	40	{35}	34	{44}	26	{53}	44	{62}	45
{9}	40	{18}	19	{27}	60	{36}	13	{45}	50	{54}	29	{63}	65

Between some coalitions there is synergy and the number of transporters required is significant less than in the case of individual transportation. Some coalitions do show almost no synergy.
The results are visualized in Figure 19, Figure 20 and Figure 21. The dotted line shows the cost in the case of individual transportation. In the case of AGV and MTS, there is always a cost saving even when the coalition consists of only one player. In the case of trucks, single player coalitions are on the dotted line.

The characteristics of the game (Table 18) show that the game is admissible and the Core is not empty in the case of a shared truck solution. In the case of AGV, the game is admissible but the

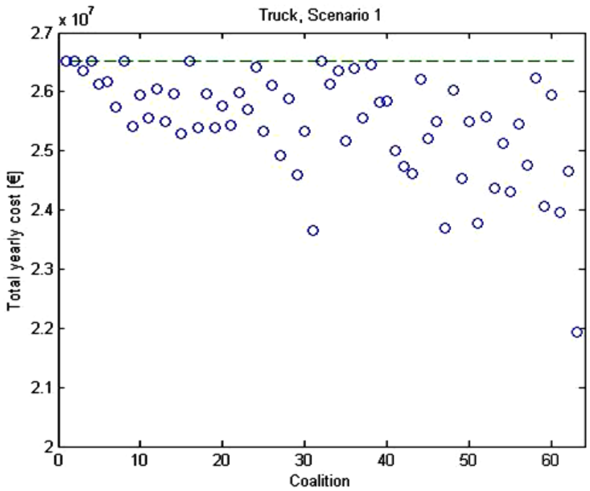

Figure 19: Cost of each coalition reduced transporters (Truck, Scenario 1)

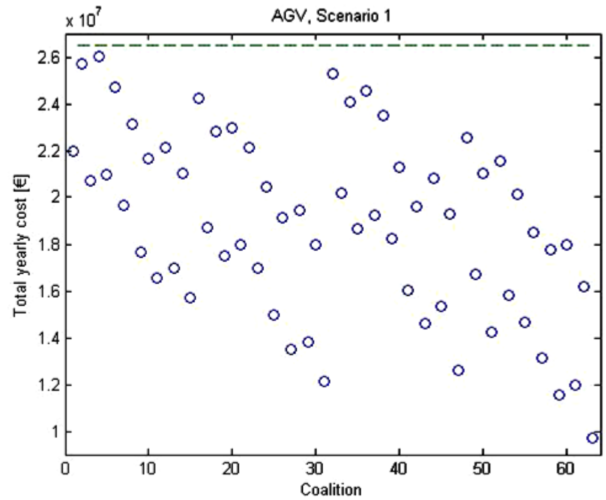

Figure 20: Cost of each coalition reduced transporters (AGV, Scenario 1)

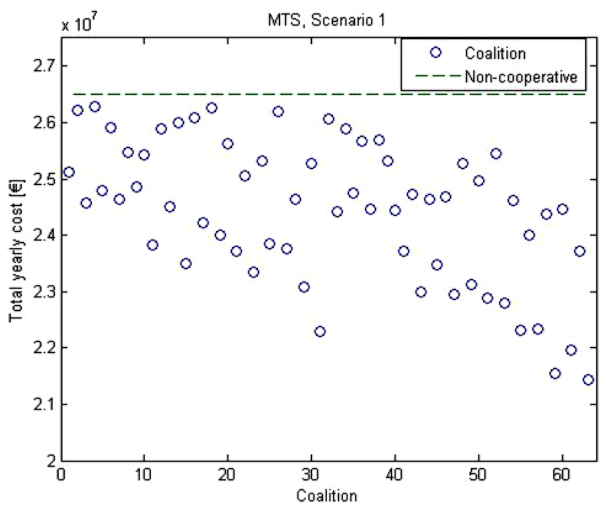

Figure 21: Cost of each coalition reduced transporters (MTS, Scenario 1)

cost allocations are not in the Core. In the case of the MTS, the game is not admissible. Moreover, Table 18 shows that the games are not super additive, monotonic, and convex. This means that there are coalitions possible where adding an extra player does not lead more cost savings. In the case of trucks adding player {2} to the coalition {1,4} the cost decrease of the coalition {1,2,4} (€ 954,973) is less than the sum of the cost decrease of coalition {2}(€ 0) and {1,4}(€ 1,101,783). There is no incentive for coalition {1,4} to let player 2 join. In the case of coalition {2,3} (€ 336,222) and coalition {2,3,6} (€ 44,530) there is also no cost decrease for adding player 6. The game is therefore not monotonic. The main reason for the game to be not monotonic, super additive or convex is the dispatching rule. If there is no synergy between the players, the dispatching rule sends the transporters to where the most containers are waiting. That can result in long empty rides, which would not take place when that player is alone. The game is essential, but not degenerative which means that the grand coalition will results in the most cost savings.

Table 18: Game characteristics from reduced transporters (scenario 1)

	Truck	AGV	MTS
Super additive	No, {2} and {9}	No, {2} and {56}	No, {1} and {6}
Monotonic	No, {6} and {38}	No, {51} and {55}	No, {1} and {39}
Convex	No, {2} and {9}	No, {2} and {56}	No, {1} and {6}
Essential	Yes	Yes	Yes
Degenerative	No	No	No
Admissible	Yes	Yes	No

For the truck it is possible to find a cost allocation that is in the Core (Table 19). The cost allocations show that player 1 and 4 contribute the most to the cost savings. The Shapley value in the case of the truck assigns more to player 1 and player 4. The tau-value distributes the cost savings more equally. The same pattern is seen with the AGV, however the cost allocation are not in the Core.

The m benefit allocation shows the minimum that player should get from the benefit allocation. In the case of the truck, the m is per definition zero because the cost savings are compared to the case of individual players performing ITT by truck. Therefore stepping out of the coalition will always result to the same cost and therefore the payoff function is zero. In the case of the AGV and the MTS, players can get a cost savings by forming a one-player coalition and execute ITT transportation by AGV or MTS. The M benefit allocation shows the threat value. The M value represents the cost savings that are missed when this player does not join the grand coalition.

Table 19: Benefit allocations in million € (scenario 1)

	Player	Core	1	2	3	4	5	6	Total
Truck	M	-	2.74	2.02	2.14	2.39	1.77	1.73	12.79
	m	-	0	0	0	0	0	0	0
	Shapley value	Yes	1.12	0.63	0.58	0.79	0.77	0.70	4.59
	Tau value	Yes	0.98	0.73	0.77	0.86	0.63	0.62	4.59
AGV	M	-	6.44	2.26	1.84	4.95	2.89	2.41	20.79
	m	-	4.91	0.81	0.63	3.37	2.28	1.23	13.23
	Shapley value	No	5.51	1.47	1.00	4.06	2.90	1.85	16.79
	Tau value	No	5.63	1.49	1.20	4.11	2.57	1.78	16.79
MTS	M	-	2.29	0.54	0.12	0.89	1.52	0.87	6.23
	m	-	1.59	0.48	0.23	1.21	0.86	1.19	5.56
	Shapley value	No	1.82	0.32	0.27	0.91	0.95	0.82	5.09
	Tau value	No	-	-	-	-	-	-	-

Independent of the chosen ITT configuration, player 1 (ECT) will get the highest benefit allocated according to the Tau value and Shapley value. In the case of truck and AGV, player 4 (Kramer) has the highest benefit allocated followed by player 5 (common services). For the MTS the order is reversed. The players 1, 4 and 5 own one or more barge or rail terminals, which create a lot of ITT traffic. Only the creation of a lot of ITT traffic will result in large cost savings. Therefore, the power in the ITT problem is more with the barge and rail terminal owners than with the deep sea container terminals. The benefit allocations will be similar for the scenarios 2 and 3. However, the demand of containers is lower and the cost savings will also be lower.

To value the collaboration of the important players in the coalition, the Port of Rotterdam Authority should assign a larger proportion of the cost savings to those players. The Port of Rotterdam Authority has negotiation space from the chosen cost allocation rule, Shapley value or tau value, up to the threat value (M value). The extra assigned benefit will be diminished from the benefit allocation of the less important players.

Chapter 6 Conclusion

A simulation model is built to analyse the inter terminal transport (ITT) system for different demands, different types of transporters and different coalitions. Results are obtained for three scenarios, where scenario 1 has a high demand and a high peak factor. The total number of containers transported is 3.34 million per year. Scenario 2 has a medium demand with reduced peak factor with a total of 2.15 million containers. Scenario 3 has low demand with no peak factor and the demand of containers is equal to 1.42 million per year. Three types of transporters are analysed namely, a shared pool of trucks, an automated guide vehicle (AGV) and a multi trailer service (MTS). The simulation model is also able the analyze effect of different coalitions on the total cost of the ITT system.

With the simulation model, it is possible to determine the amount of transporters required for each container demand scenario. The truck and AGV require 70 transporters for scenario 1, 41 transporters for scenario 2 and 27 transporters for scenario 3. An ITT system transporting containers with MTS with a capacity of 10 TEU requires 60 transporters for scenario 1, 36 transporters for scenario 2 and 24 transporters for scenario 3.

A cost function is applied to the results of the simulation to determine the total yearly cost. The cost of individual transportation can be compared to collaborative solutions. For each scenarios and each transporter type is the cost of individual transportation higher than a collaborative solution. From the collaborative solutions is the AGV the most cost efficient solution. The total yearly cost of an AGV solution is 9.5 million for scenario 1, 6.0 million for scenario 2 and 3.9 million for scenario 3. The cost reduction is caused by the abundance of wage cost. The cost of a pool of shared trucks is 21.5 million, 12.9 million and 8.7 million for scenario 1, 2 and 3 respectively. In the case of the MTS the cost for the scenarios 1,2 and 3 are 21.2 million, 13.8 million and 9.4 million. Comparing the manned transportation solutions, the truck is favourable in the case of scenario 2 and 3. The MTS is preferred in the case of a demand according to scenario 1. The extra loading capacity of the MTS pays only off when the demand of containers is high and the transporters are efficiently dispatched.

Results from the simulation model can be obtained for different coalitions of players in the ITT problem. The results are analysed with game theory to find the contribution of each player to the cost savings compared to individual transportation. The results show that the players 1 (ECT) and 4 (Kramer) contribute the most to the cost savings in a coalition, followed by player 5 (common services). Both players own a barge or rail facility that creates many ITT movements. The Port of Rotterdam Authority should identify the importance of the commitment of player 1 and 4 early in the ITT system design process. The common rail and barge terminal are required to create the container volume to consider other ITT configurations than the shared pool of trucks. To value the important players, the Port of Rotterdam Authority can assign a larger proportion of the cost savings.

Chapter 7 Discussion and limitations

The number of containers that will be handled by the ITT system and their arrival times is uncertain. Therefore, three different scenarios are constructed. The container is the lowest level of analysis, resulting in the ignorance of correlation between containers. In reality, containers arrive by the same deep sea vessel, barge or train. If for example the deep sea vessel is too late because of bad weather all containers on that vessel are too late. Many containers with small due times will enter the ITT system. This will create dynamic patterns in the ITT system. This behaviour is not incorporated in the simulation model used in this study. To include the correlation of containers, a generator model need to be constructed that simulates the arrival and departure patterns of deep sea vessels, barges and trains. Based on these arrival and departure patterns the arrival of individual containers in the ITT system can be obtained.

Beside the demand of containers, the due time distribution is also uncertain. The due time distribution as applied does not take the travel time into account. Therefore, it is possible to allocate a due time to a container that is less than the travel time to deliver the container. Adding a fixed minimum time to the due time distribution will solve this issue. The penalty cost in the results will be reduced.

The timing of the arrival of a container at the destination terminal is also important. If the container arrives too early, it has to be stored in a container stack. The terminal needs a large stack to store early arriving containers and stored containers require extra handling costs. In the simulation, the terminals have an unlimited stack to store containers. The influence of the container stack size on the performance of the ITT system could be significant. The simulation model could be extended by applying arrival windows for containers and planning system of transporters to deliver the containers within the arrival window. The simulation does also not take into account the 'normal' terminal operations. Assumed is that the ITT system has own cranes that do not interfere with other processes at the terminal. In reality, the ITT containers will be handled at the same cranes as non-ITT containers. The simulation is not validated but verified by a visual animation. Because there is nothing like the proposed ITT system, results can in best compared to other simulation studies. Furthermore, the grouping of terminals in six players is based on the current situation. It could be that merger and acquisitions change the ownership of terminals. This will have influence on the coalitional behaviour of the ITT problem. The ITT simulation is able to analyse a different set of players.

Based on the cost function, the AGV is the most cost effective solution. The container demand scenarios are based on the situation on the year 2030, when full capacity will be realized. Leading to the years 2030, the ITT system will function under full capacity. The AGV solution requires a large investment up front because of the development in technology. AGV's are applied for more than 30 years on terminals but not between terminals. Only a certain amount of container flows will justify the investment in infrastructure. Terminals with small container flows and/or remote locations, like the terminals 8, 9, 15, 16 and 18, will probably not be connected to an AGV solution. A MTS system requires more planning than a truck or AGV solution. The trailers of MTS can be loaded before hand and coupled to the tractor at the terminal. This is not taken into account in the simulation model. The coupling and decoupling of trailers lead to a higher utilization of the tractor, which is the most costly part of the MTS. The cost function does also not address the cost of handling at the terminal and the infrastructure cost. These costs can also influence the results of the study.

The dispatching rule used steers upon number of container waiting, minimal driving distance and timeliness of containers. The dispatching rule does not steer upon minimum throughput time of containers, of which the waiting time is the largest part. Aligning the steering element of the simulation with the cost function and the required number of transporters will probably result in monotonic behaviour. The chance that the Core is not empty and benefit allocations that are situated in the Core will be increased.

The cost comparison between the different ITT configurations excludes the cost of infrastructure because all ITT configurations use the internal road. However, the truck can also use the public road and therefore exclude the cost of infrastructure. Figure 22 shows the cost comparison between the truck that don't need separate infrastructure and the AGV which is the cheapest solution considering an internal road. Based on infrastructure cost of € 1,167 per m road and €500,000 per crossing (Diekman and Koeman, 2010) and a depreciation time of 30 years (see Appendix 8), the total yearly cost is € 3,616,000. In the case of scenario 3, the total yearly cost is almost the same but slightly in favour of the AGV. With increasing container demand, the AGV solution including the infrastructure becomes more favourable than the truck solution on the public road.

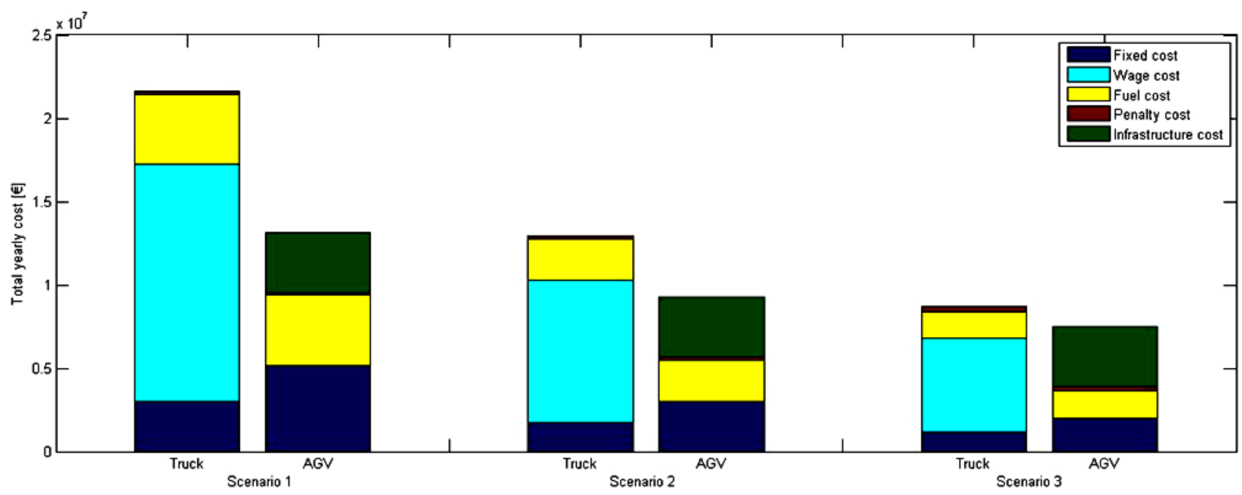

Figure 22: Cost comparison Truck and AGV including infrastructure cost

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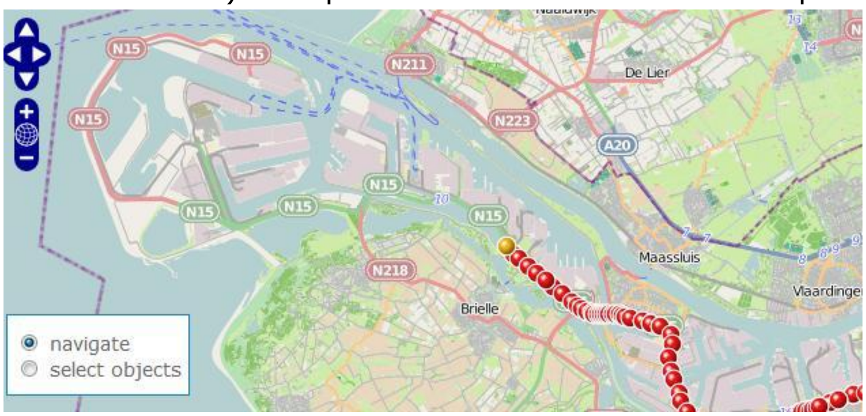
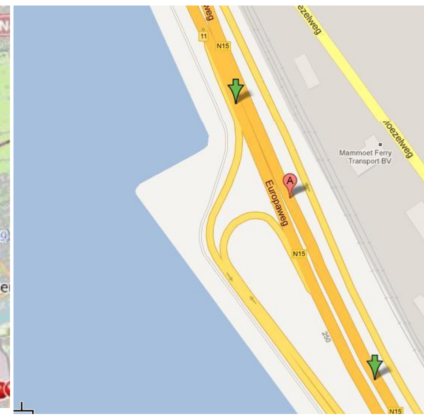
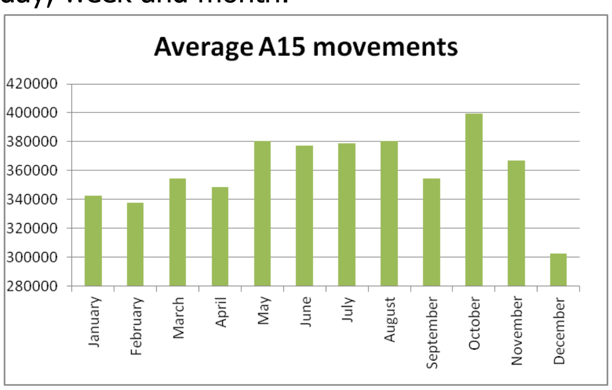
Appendix 1: Current arrivals of trucks, barges and trains at the Maasvlakte

The database of Regiolab Delft (Regiolab-Delft) holds data per minute from loop detectors of the highways in the province Zuid Holland. As can be seen in the figure below, the traffic data is obtained from the closest point available to the Maasvlakte Area. The two detector points (one for each direction) are separated with an on and off road ramp.

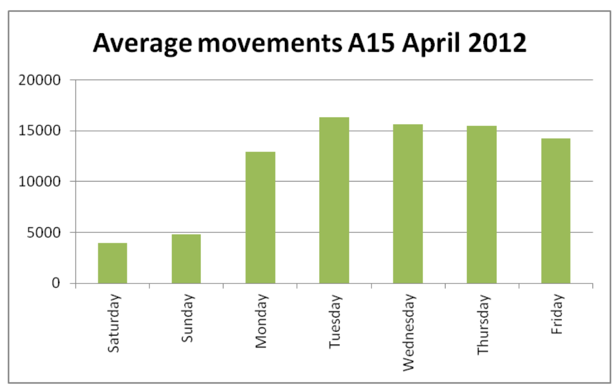




The movement data is used to find monthly, weekly and daily patterns for container movements. The data is biased because movements are caused by trucks but also by cars. Commuter traffic is more or less excluded, because of the industrial nature of the Maasvlakte Area. The results of the A15 movements give a feeling about the distribution patterns over the day, week and month.

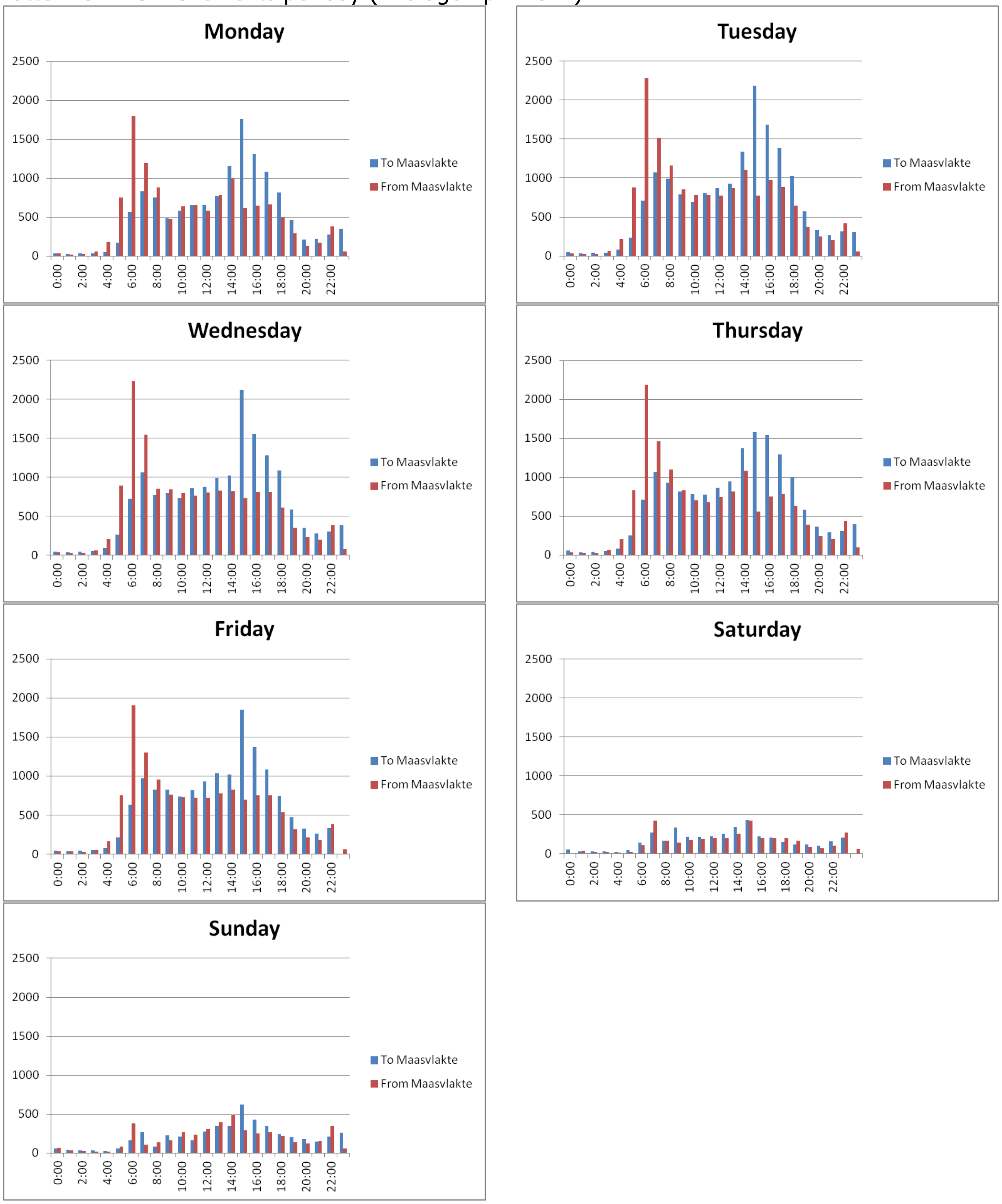


Monthly pattern of A15 movements in 2012



Week pattern of A15 movements in April 2012

Pattern of A15 movements per day (Average April 2012)



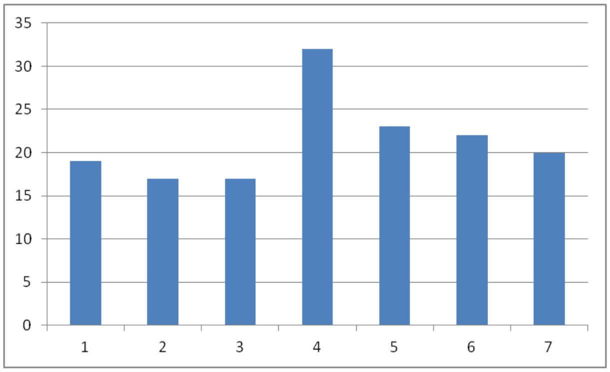


Figure 23: Number of barges visiting APM MV1 terminal per weekday

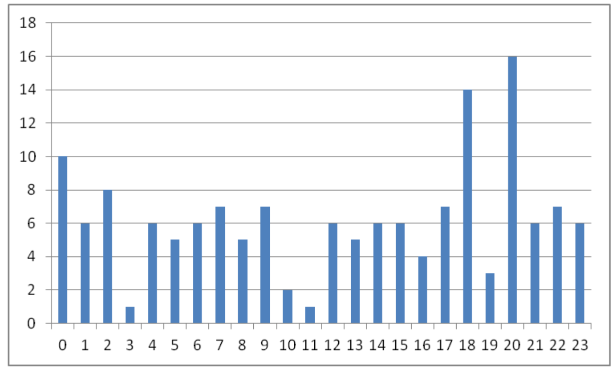


Figure 24: Number of barges visiting APM MV1 terminal per hour of the day

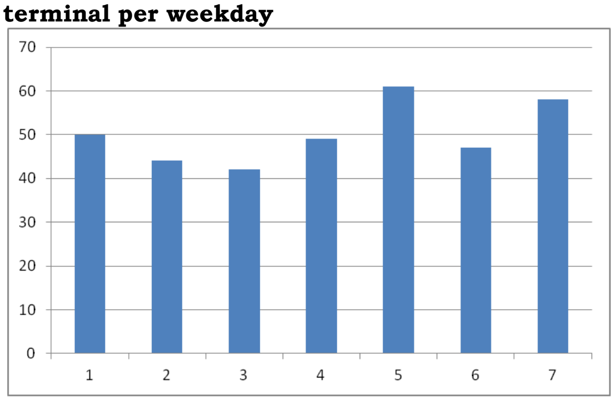


Figure 25: Number of barges visiting ECT Delta terminal per weekday

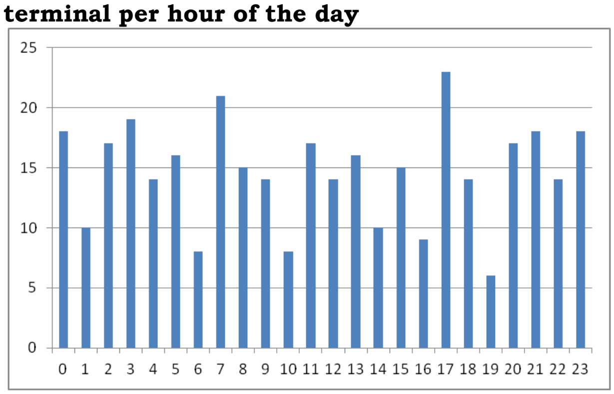


Figure 26: Number of barges visiting ECT Delta terminal per hour of the day

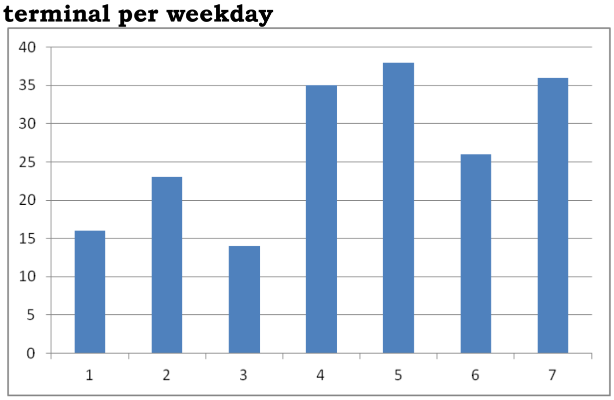


Figure 27: Number of barges visiting Euromax terminal per weekday

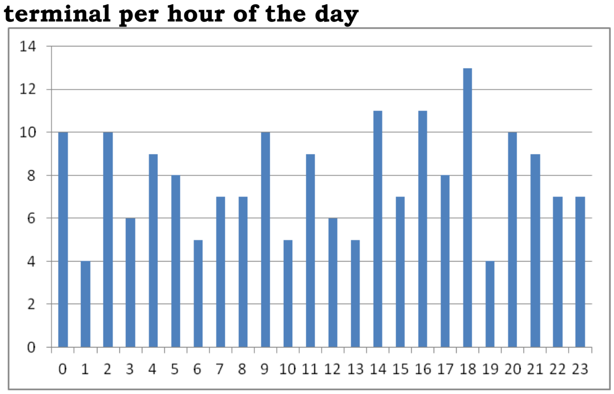


Figure 28: Number of barges visiting Euromax terminal per hour of the day

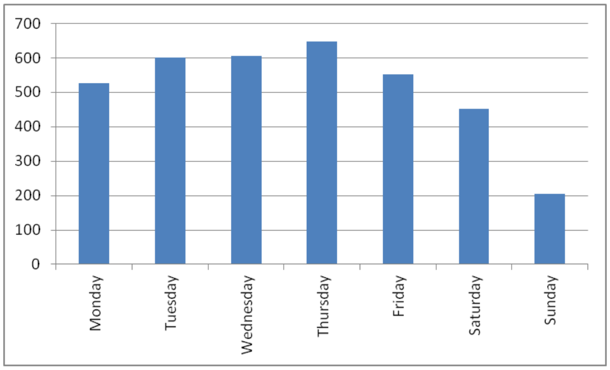


Figure 29: Number of trains visiting the Maasvlakte per weekday

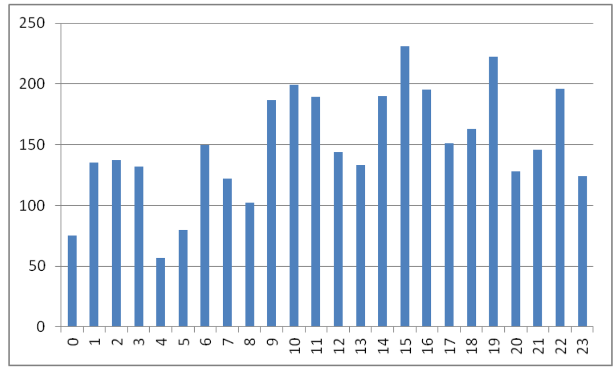


Figure 30: Number of trains visiting the Maasvlakte per hour of the day

Appendix 2: Construction of a scenario

To / From	Deep sea terminals	Barge Terminals	Rail Terminals	Customs	Empty depots
Deep sea terminals	94000[1]	425865[4]	628690[3]	155000[2]	266175[5]
Barge terminals	283910[4]	0	0	0	146396[4,5]
Rail terminals	943035[3]	0	0	0	119779[3,5]
Customs	155000[2]	0	0	0	0
Empty depots	494325[5,8]	78829[4,5,6]	64496[3,5,7]	0	0

[1] The demand from deep sea terminal to deep sea terminal is in scenario 1, 1% of the 9.4 million transhipment containers from the global economy prediction (94,000 TEU).
[2] The demand to customs is equal to 0.5% (155,000 TEU) of the total container handled (31.0 million TEU). A container from customs creates two ITT movements to and from the scan.
[3] The total capacity of the rail terminals is 1.756 milllion TEU
[4] The total capacity of the barge terminals is 0.935 milllion TEU
[5] The total capacity of the empty depot is 1.17 milllion TEU
[6] The total capacity of empty depots is multiplied the import ratio of empty containers (35%). The majority of empty containers will be send to deep sea terminals (65%) and only 35% to barge and rail terminals. Assumed is that 55% goes via the barge terminal. Of the 1.17 million empty depot containers, 78829 will leave by a barge terminal (1170000*0.35*0.35*0.55 = 78829).
[7] The total capacity of empty depots is multiplied the import ratio of empty containers (35%). The majority of empty containers will be send to deep sea terminals (65%) and only 35% to barge and rail terminals. Assumed is that 45% goes via the rail terminal. Of the 1.17 million empty depot containers, 64496 will leave by a rail terminal (1170000*0.35*0.35*0.45 = 64496).
[8] From an empty depot to a deep sea terminal is an empty export container. The total capacity of empty depots is multiplied the export ratio of empty containers (65%). The majority of empty containers will be send to deep sea terminals (65%). This results in 494325 ITT movements. (1170000*0.65*0.65= 4943285).

Appendix 3: The Origin/Destination matrices for the three scenarios

Table 20: Scenario 1, demand for ITT transport (OD-matrix) [TEU/year]

Participant	ECT Delta Terminal	Euromax Terminal	APM MV1 Terminal	Rotterdam World Gateway	APM MV2 Terminal	T3	T4	ECT Delta barge Feeder terminal	Delta Container Services	Common Rail Terminal	Rail Terminal West	Rotterdam Container Terminal Hartelhaven	Common Barge Service Center	Kramer Delta depot	Van Doorn Container depot	Empty depot MV1	Empty depot MV2	Customs
ECT Delta Terminal	x	3905	2580	3096	3572	3096	2560	397	119	66687	62559	47754	39795	7107	9645	12183	25787	9662
Euromax Terminal	3696	x	1907	2288	2640	2288	0	293	88	52080	48855	37294	31078	5550	7532	0	20138	7546
APM MV1 Terminal	2293	1790	x	1419	1638	1419	1174	182	55	34402	32272	24635	20529	3666	4975	6285	13303	4984
Rotterdam World Gateway	2818	2201	1454	x	2013	0	1443	224	67	41283	38727	29562	24635	4399	5970	7542	15963	5981
APM MV2 Terminal	3326	2598	1716	2059	x	2059	1703	264	79	0	44685	34110	28425	5076	6889	8702	0	6902
T3	2818	2201	1454	0	2013	x	1443	224	67	41283	38727	29562	0	4399	5970	7542	15963	5981
T4	2273	0	1173	1407	1623	1407	x	180	54	34138	32024	24446	20371	3638	4937	6236	13200	4946
ECT Delta barge Feeder terminal	321	250	165	198	229	198	164	x	8	5293	4965	3790	3158	564	765	967	2047	767
Delta Container Services	95	74	49	59	68	59	49	8	x	1588	1489	1137	948	169	230	290	614	230
Common Rail Terminal	100031	78120	51603	61924	0	61924	51206	7939	2382	x	0	0	0	8026	10893	13759	0	0
Rail Terminal West	93838	73283	48408	58090	67027	58090	48036	7447	2234	0	x	0	0	7529	10218	12907	27321	0
Rotterdam Container Terminal	31836	24862	16423	19708	22740	19708	16297	2527	758	0	0	x	0	10370	14074	17778	37630	0
Common Barge Service Center	26530	20719	13686	16423	18950	0	13581	2106	632	0	0	0	x	8642	11728	14815	31358	0
Kramer Delta depot	13198	10307	6808	8170	9427	8170	6756	1047	314	4322	4054	5584	4653	x	0	0	0	0
Van Doorn Container depot	17911	13988	9240	11088	12794	11088	9169	1422	426	5865	5502	7578	6315	0	x	0	0	0
Empty depot MV1	22625	0	11672	14006	16161	14006	11582	1796	539	7409	6950	9573	7977	0	0	x	0	0
Empty depot MV2	47889	37399	24705	29646	0	29646	24515	3801	1140	0	14711	20262	16885	0	0	0	x	0
Customs	9662	7546	4984	5981	6902	5981	4946	767	230	0	0	0	0	0	0	0	0	x

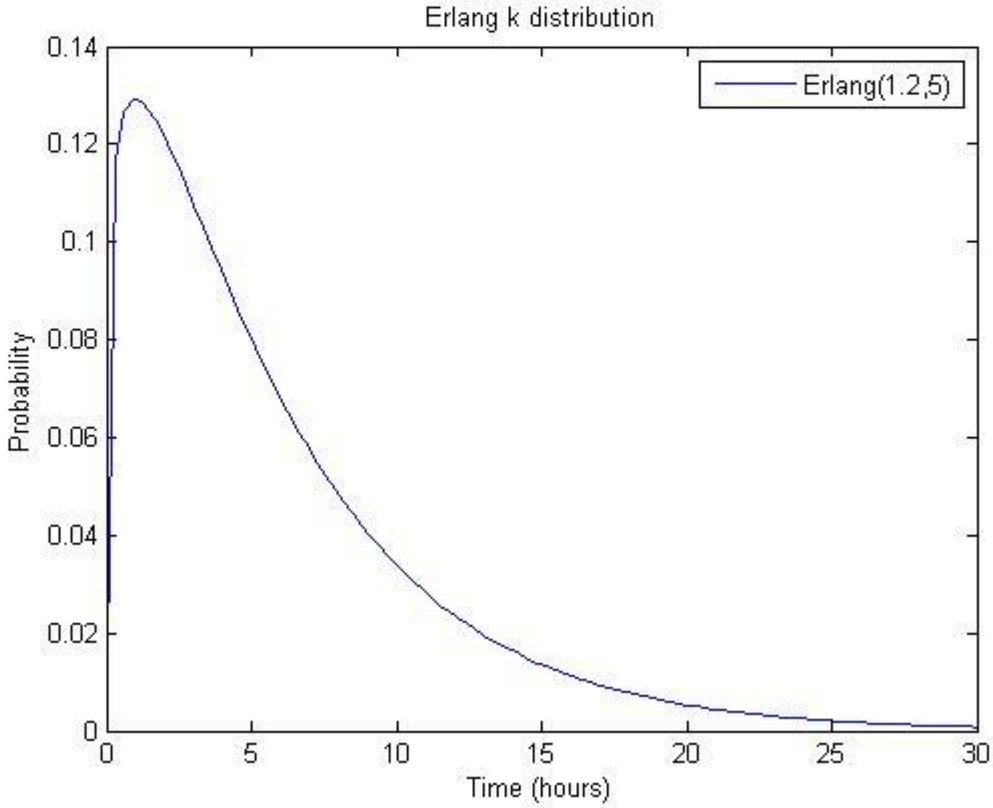
Table 21: Scenario 2, demand for ITT transport (OD-matrix) [TEU/year]

Participant	ECT Delta Terminal	Euromax Terminal	APM MV1 Terminal	Rotterdam World Gateway	APM MV2 Terminal	T3	T4	ECT Delta barge Feeder terminal	Delta Container Services	Common Rail Terminal	Rail Terminal West	Rotterdam Container Terminal Hartelhaven	Common Barge Service Center	Kramer Delta depot	Van Doorn Container depot	Empty depot MV1	Empty depot MV2	Customs
ECT Delta Terminal	x	4239	0	2688	3102	2688	2223	0	0	57907	53453	0	26855	0	7925	10011	21189	4575
Euromax Terminal	3981	x	2053	1971	2275	1971	0	316	95	45223	41744	25633	20972	4560	6189	0	16548	3573
APM MV1 Terminal	0	1912	x	1213	1399	1213	1003	0	0	29873	27575	0	13854	0	4088	5164	10931	2360
Rotterdam World Gateway	2338	1826	1206	x	1336	0	958	186	56	28678	26472	16255	13300	2892	3925	4958	10494	2266
APM MV2 Terminal	2752	2149	1420	1363	x	1363	1127	218	66	0	30544	18756	15346	3337	4529	5720	0	2614
T3	2338	1826	1206	0	1336	x	958	186	56	28678	26472	16255	0	2892	3925	4958	10494	2266
T4	1892	0	976	937	1081	937	x	150	45	23714	21890	13442	10998	2391	3246	4100	8678	1874
ECT Delta barge Feeder terminal	0	264	0	168	193	168	139	x	0	4596	4242	0	2131	0	629	794	1682	363
Delta Container Services	0	78	0	50	57	50	41	0	x	1379	1273	781	639	139	189	238	505	109
Common Rail Terminal	70775	55272	36511	35051	0	35051	28984	5617	1685	x	0	0	0	5973	8107	10240	0	0
Rail Terminal West	65331	51020	33703	32354	37332	32354	26755	5185	1556	0	x	0	0	5514	7483	9452	20008	0
Rotterdam Container Terminal	0	20972	0	13300	15346	13300	10998	0	639	0	0	x	0	0	10480	13238	28020	0
Common Barge Service Center	21972	17159	11335	10881	12556	0	8998	1744	523	0	0	0	x	6318	8574	10831	22925	0
Kramer Delta depot	0	6841	0	4338	5005	4338	3587	0	209	3982	3676	0	4212	x	0	0	0	0
Van Doorn Container depot	11888	9284	6133	5887	6793	5887	4868	943	283	5404	4989	6987	5716	0	x	0	0	0
Empty depot MV1	15016	0	7746	7437	8581	7437	6149	1192	358	6827	6302	8825	7221	0	0	x	0	0
Empty depot MV2	31784	24822	16396	15741	0	15741	13016	2523	757	0	13338	18680	15284	0	0	0	x	0
Customs	4575	3573	2360	2266	2614	2266	1874	363	109	0	0	0	0	0	0	0	0	x

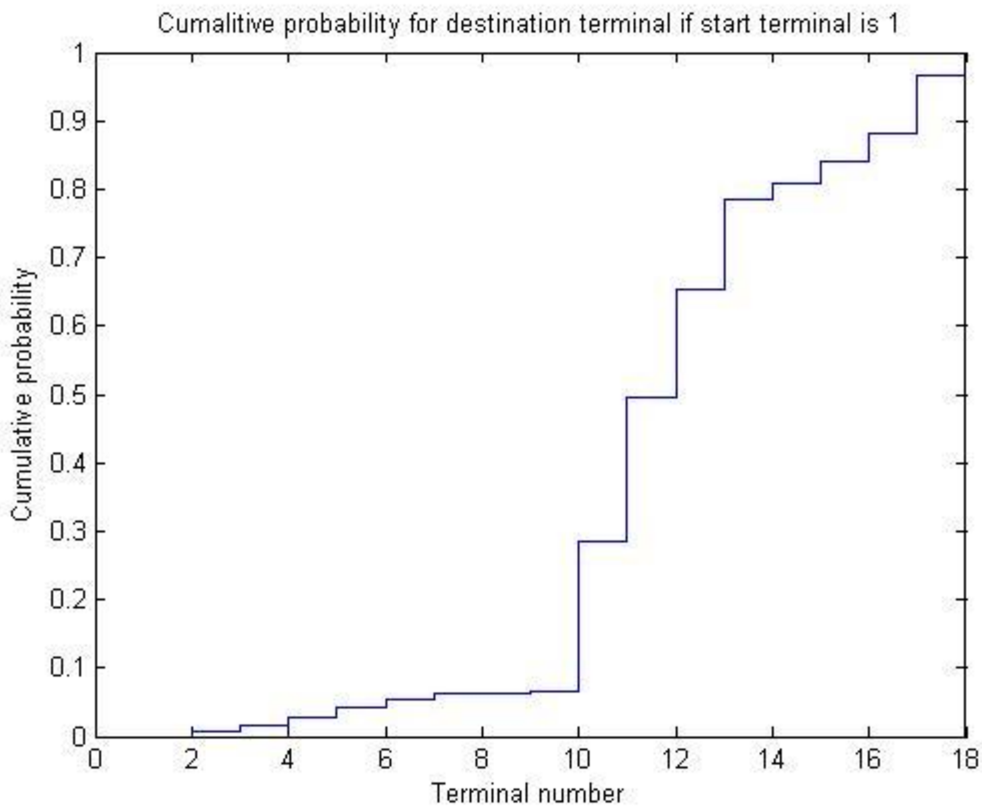
Table 22: Scenario 3, demand for ITT transport (OD-matrix) [TEU/year]

Participant	ECT Delta Terminal	Euromax Terminal	APM MV1 Terminal	Rotterdam World Gateway	APM MV2 Terminal	T3	T4	ECT Delta barge Feeder terminal	Delta Container Services	Common Rail Terminal	Rail Terminal West	Rotterdam Container Terminal Hartelhaven	Common Barge Service Center	Kramer Delta depot	Van Doorn Container depot	Empty depot MV1	Empty depot MV2	Customs
ECT Delta Terminal	x	4239	0	2688	3102	2688	2223	0	0	0	50110	0	0	0	7925	10011	21189	4575
Euromax Terminal	3981	x	2053	1971	2275	1971	0	316	95	0	39133	17374	0	4560	6189	0	16548	3573
APM MV1 Terminal	0	1912	x	1213	1399	1213	1003	0	0	0	25850	0	0	0	4088	5164	10931	2360
Rotterdam World Gateway	2338	1826	1206	x	1336	0	958	186	56	0	24816	11018	0	2892	3925	4958	10494	2266
APM MV2 Terminal	2752	2149	1420	1363	x	1363	1127	218	66	0	28634	12713	0	3337	4529	5720	0	2614
T3	2338	1826	1206	0	1336	x	958	186	56	0	24816	11018	0	2892	3925	4958	10494	2266
T4	1892	0	976	937	1081	937	x	150	45	0	20521	9111	0	2391	3246	4100	8678	1874
ECT Delta barge Feeder terminal	0	264	0	168	193	168	139	x	0	0	3977	0	0	0	629	794	1682	363
Delta Container Services	0	78	0	50	57	50	41	0	x	0	1193	530	0	139	189	238	505	109
Common Rail Terminal	0	0	0	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0
Rail Terminal West	61245	47830	31595	30331	34997	30331	25081	4861	1458	0	x	0	0	11487	15590	19692	41682	0
Rotterdam Container Terminal	0	14215	0	9014	10401	9014	7454	0	433	0	0	x	0	0	19054	24069	50945	0
Common Barge Service Center	0	0	0	0	0	0	0	0	0	0	0	0	x	0	0	0	0	0
Kramer Delta depot	0	6841	0	4338	5005	4338	3587	0	209	0	7658	0	0	x	0	0	0	0
Van Doorn Container depot	11888	9284	6133	5887	6793	5887	4868	943	283	0	10393	12703	0	0	x	0	0	0
Empty depot MV1	15016	0	7746	7437	8581	7437	6149	1192	358	0	13128	16046	0	0	0	x	0	0
Empty depot MV2	31784	24822	16396	15741	0	15741	13016	2523	757	0	27788	33963	0	0	0	0	x	0
Customs	4575	3573	2360	2266	2614	2266	1874	363	109	0	0	0	0	0	0	0	0	x

Appendix 4: Due time distribution



Appendix 5: Discrete probability of destination terminal



Appendix 6: Terminal capacity and backdoor connections

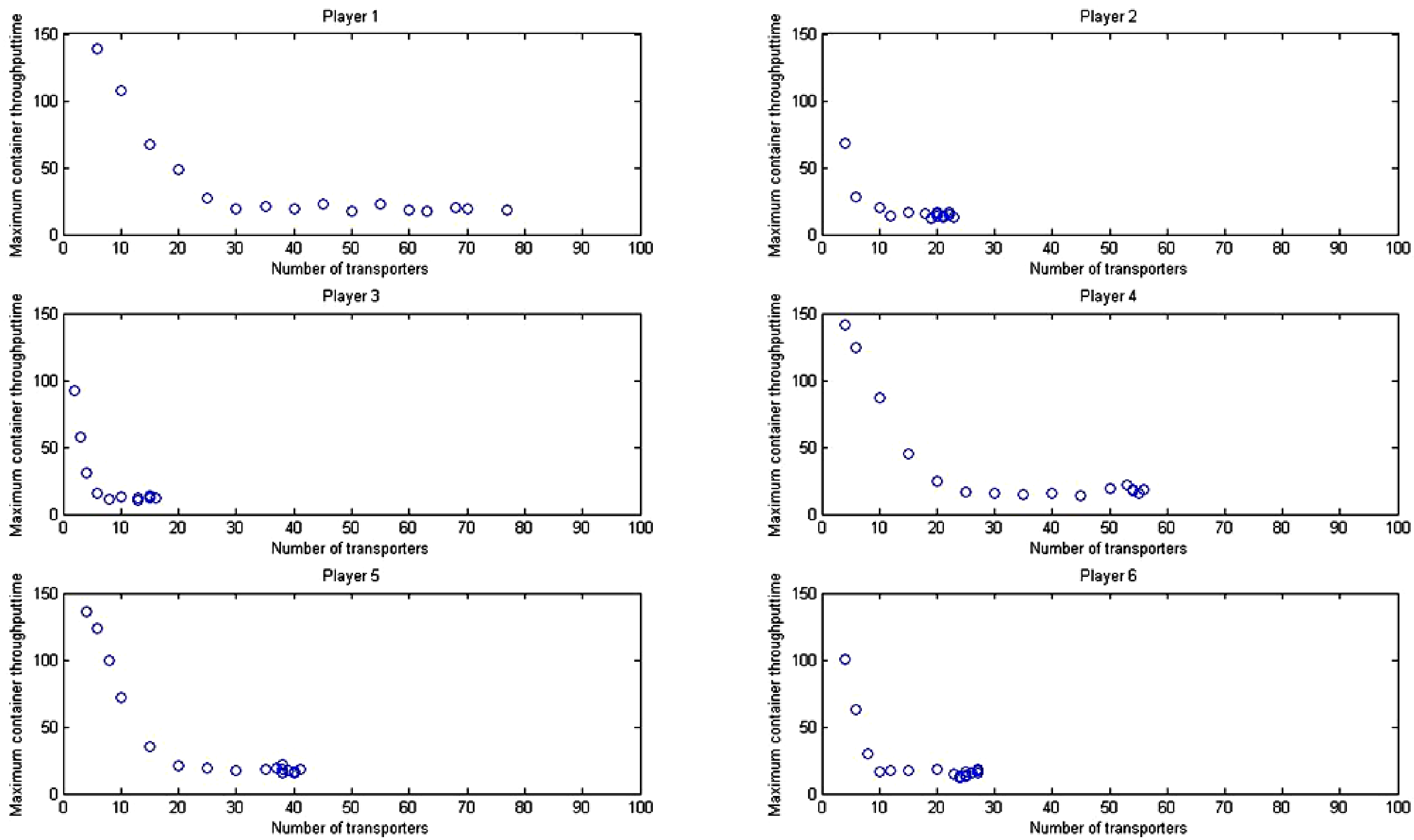
Player	Terminal	Name	Deep sea terminal	Common Rail Terminal	Common Barge Terminal	Empty depot	Customs	Capacity
1	1	ECT Delta Terminal	X					6300000
	2	Euromax Terminal	X					4920000
	8	ECT Delta Barge Feeder Terminal	X					500000
	9	Delta Container Services	X					150000
	11	Rail Terminal West		X				906000
2	3	APM MV1 Terminal	X					3250000
	5	APM MV2 Terminal	X					4500000
3	4	Rotterdam World Gateway	X					3900000
4	12	Barge Service Center Hartelhaven			X			510000
	14	Kramer Delta depot				X		140000
	15	Van Doorn Container depot				X		190000
	16	Empty depot MV1				X		248000
	17	Empty depot MV2				X		600000
5	10	Common Rail Terminal		X				850000
	13	Common Barge Service Center			X			425000
	18	Douane					X	75000
6	6	T3	X					3900000
	7	T4	X					3225000

Backdoor connections

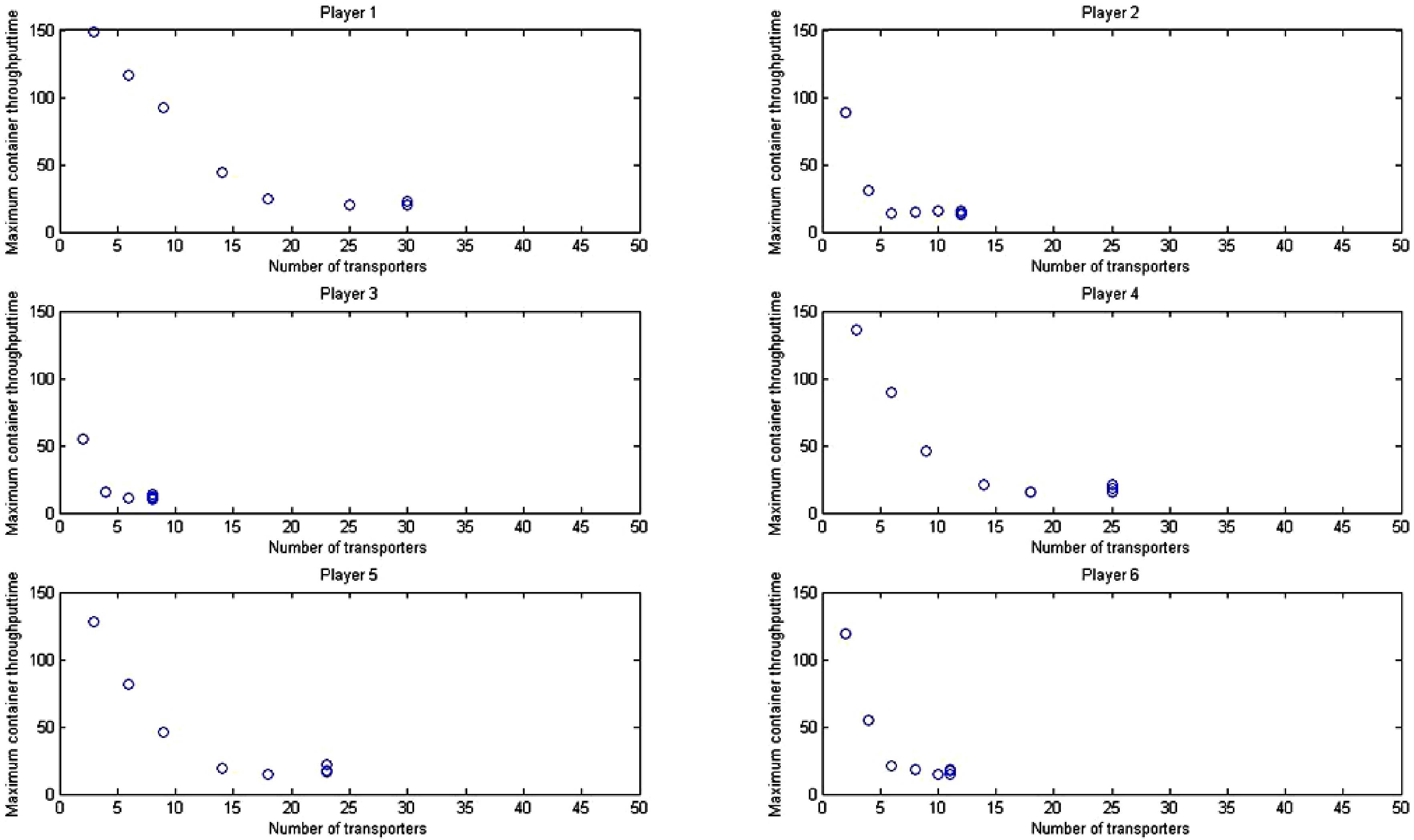
Between	and
ECT Delta (1)	APM MV1 (3)
ECT Delta (1)	ECT Delta Barge Feeder (8)
APM MV1 (3)	ECT Delta Barge Feeder (8)
ECT Delta (1)	Rotterdam Container Terminal Hartelhaven (12)
ECT Delta (1)	Kramer Delta Depot (14)
Kramer Delta Depot (14)	Delta Container Services (9)
Empty depot MV1 (16)	Euromax (2)
Euromax (2)	T4 (7)
T3 (6)	Rotterdam World Gateway (4)
T3 (6)	Common Barge Service Center (13)
Empty depot MV2 (17)	Common Rail Terminal (10)
APM MV2 (5)	Empty depot MV2 (17)
APM MV2 (5)	Common Rail Terminal (10)

Appendix 7: Number of transporters assigned

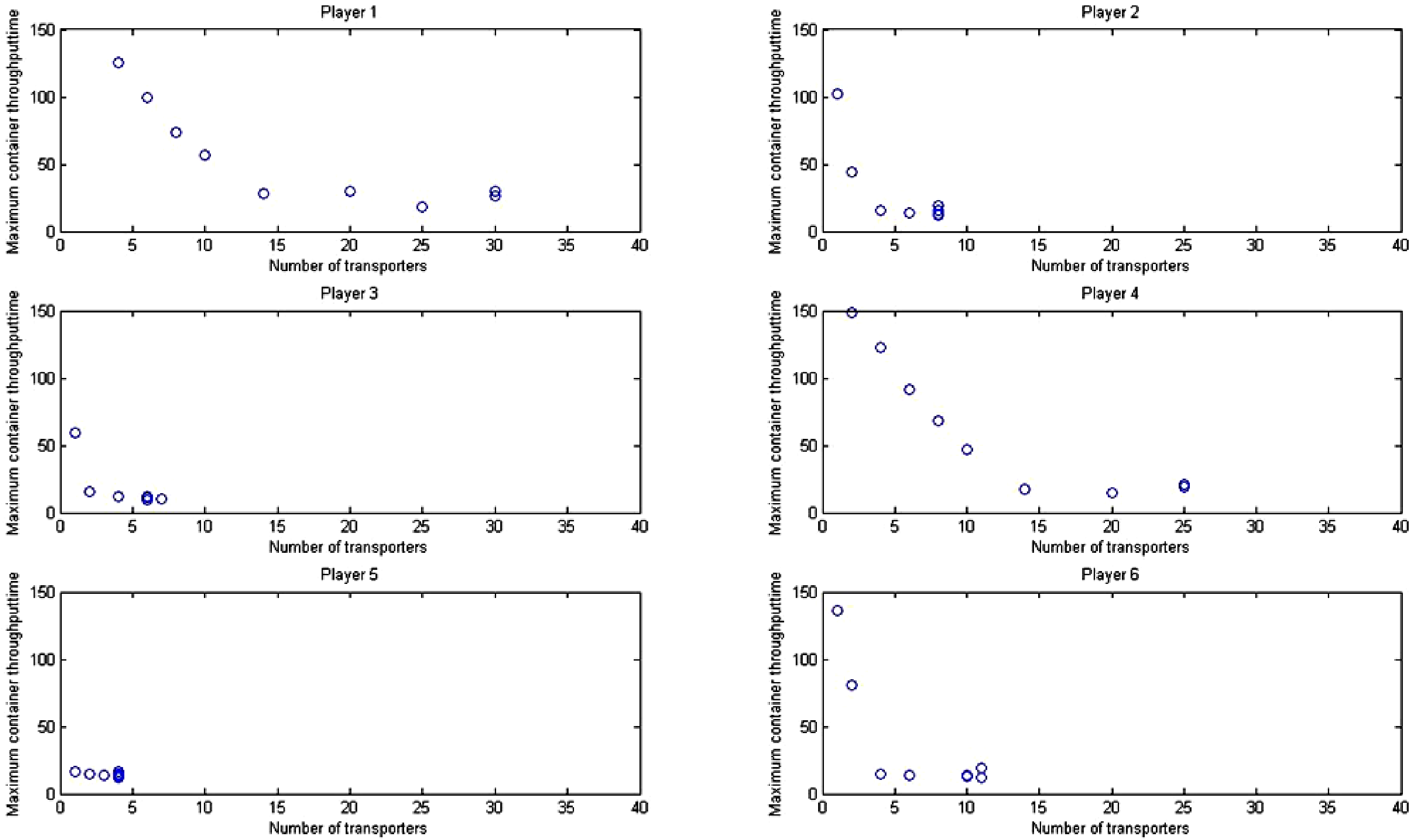
Truck and AGV, scenario 1



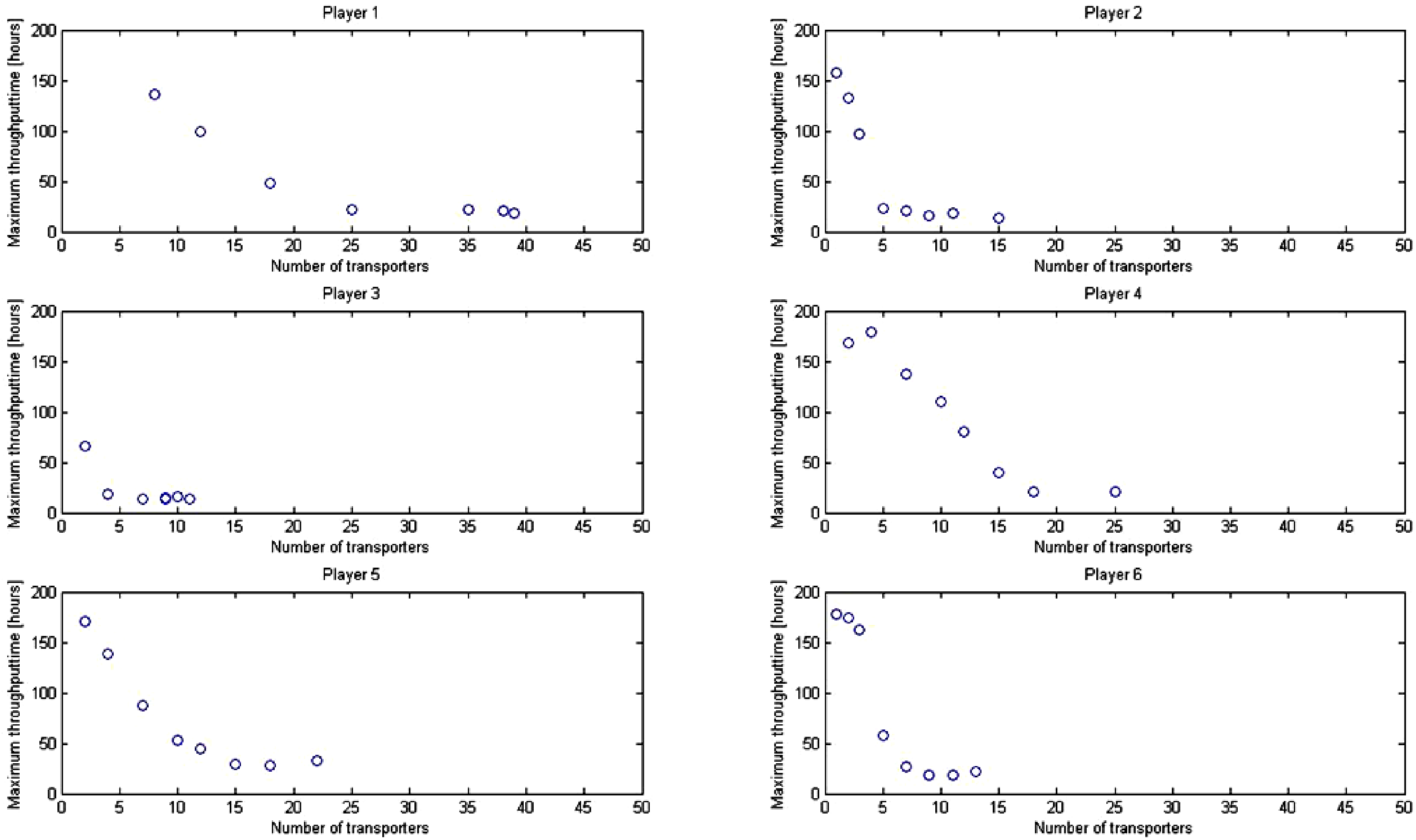
Truck and AGV, scenario 2



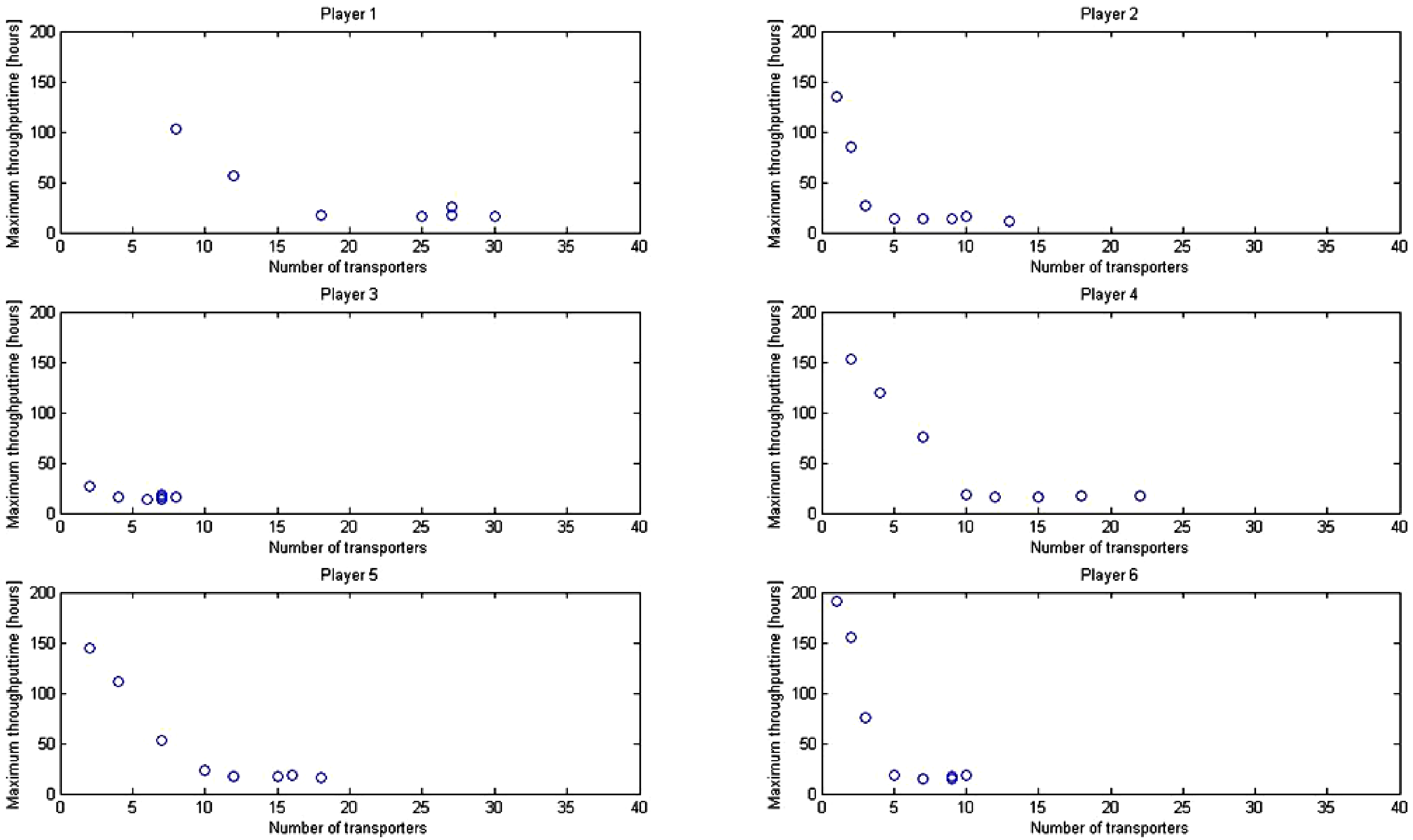
Truck and AGV, scenario 3



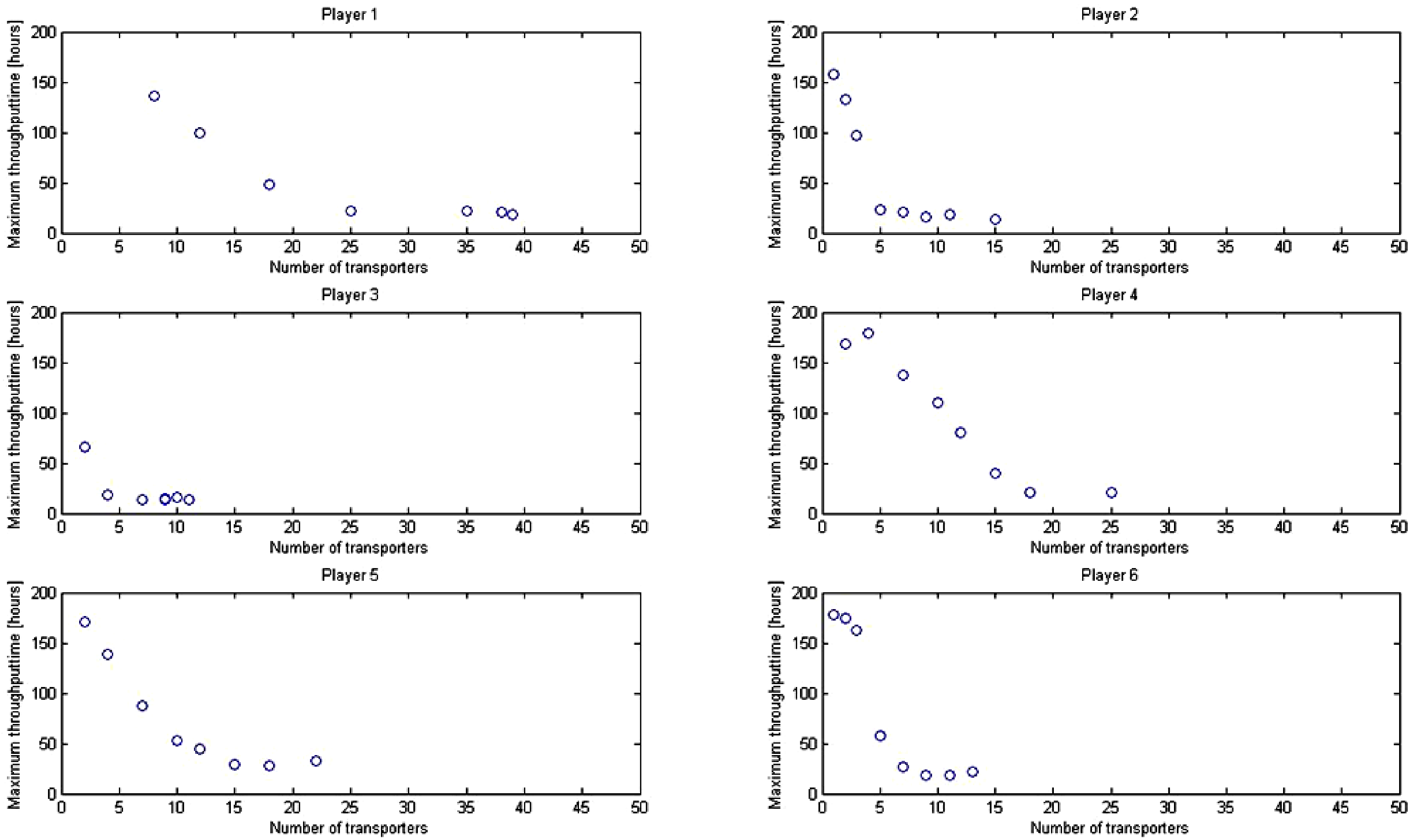
MTS, scenario 1



MTS, scenario 2



MTS, scenario 3



Appendix 8: Breakdown of transporter cost

Interest		5%				
		Truck	MTS	AGV	Infrastructure	crossings
Investment cost	€	€ 170,000	€ 350,000	€ 400,000	€ 22,289,000	€ 4,775,000
Depreciation time	Year	6	8	10	30	10
Yearly cost						
Depreciation*	€	€ 28,333	€ 43,750	€ 40,000	€ 742,967	€ 477,500
Average interest	€	€ 4,250	€ 8,750	€ 10,000	€ 557,225	€ 119,375
Maintenance cost	€	€ 10,200	€ 21,000	€ 24,000	€ 1,337,340	€ 382,000
fixcost	€	€ 42,783	€ 73,500	€ 74,000	€ 2,637,532	€ 978,875
Personnel cost	€	€ 50,000	€ 50,000	€ 0		
Wage driver (2000 hours/year)	€/hour	€ 25	€ 25	€ 0		
Penalty cost	€ /hour	€ 15	€ 15	€ 15		
Fuel cost	€/km	€ 0.25	€ 0.375	€ 0.25		

*(linear mortgage)

Appendix 9: Players in the coalitions

Coalitionnr	Players	Coalitionr	Players	Coalitionr	Players	Coalitionr	Players	Coalitionr	Players	Coalitionr	Players	Coalitionr	Players
1	1	10	2,4	19	1,2,5	28	3,4,5	37	1,3,6	46	2,3,4,6	55	1,2,3,5,6
2	2	11	1,2,4	20	3,5	29	1,3,4,5	38	2,3,6	47	1,2,3,4,6	56	4,5,6
3	1,2	12	3,4	21	1,3,5	30	2,3,4,5	39	1,2,3,6	48	5,6	57	1,4,5,6
4	3	13	1,3,4	22	2,3,5	31	1,2,3,4,5	40	4,6	49	1,5,6	58	2,4,5,6
5	1,3	14	2,3,4	23	1,2,3,5	32	6	41	1,4,6	50	2,5,6	59	1,2,4,5,6
6	2,3	15	1,2,3,4	24	4,5	33	1,6	42	2,4,6	51	1,2,5,6	60	3,4,5,6
7	1,2,3	16	5	25	1,4,5	34	2,6	43	1,2,4,6	52	3,5,6	61	1,3,4,5,6
8	4	17	1,5	26	2,4,5	35	1,2,6	44	3,4,6	53	1,3,5,6	62	2,3,4,5,6
9	1,4	18	2,5	27	1,2,4,5	36	3,6	45	1,3,4,6	54	2,3,5,6	63	1,2,3,4,5,6

Appendix 10: Results per coalition

Player	Fixcost	Wage cost	Fuel cost	Penalty cost	Individual cost
1	1283460	5471570	1810325	297180	8862535
2	513384	1158300	372483	4680	2048847
3	342256	739310	238950	3120	1323636
4	1069550	4154280	1399297	28860	6651987
5	983986	2998970	995154	54600	5032710
6	470602	1575990	535802	8580	2590974
Total					26510688

Results per coalition (Truck, Scenario 1)

Coalition	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
1	1283460	5471570	1810325	297180	8862535	17648153	0
2	513384	1158300	372483	4680	2048847	24461842	0
3	1582934	6770530	2197515	199680	10750659	15599306	160723
4	342256	739310	238950	3120	1323636	25187052	0
5	1411806	6194110	2031301	163800	9801017	16324517	385155
6	556166	1870180	600555	9360	3036261	23138205	336222
7	1668498	7291050	2341197	171600	11472345	14275670	762673
8	1069550	4154280	1399297	28860	6651987	19858702	0
9	2053536	9232860	2982043	144300	14412739	10996166	1101783
10	1240678	5193370	1682242	28080	8144370	17809855	556464
11	2353010	10738910	3429895	86580	16608395	8947320	954973
12	1155114	4761900	1563346	26520	7506880	18535065	468743
13	2267446	10174970	3262619	109980	15815015	9672530	1023143
14	1497370	6010030	1946901	28860	9483161	16486219	541309
15	2524138	11442080	3626159	77220	17669597	7623683	1217408
16	983986	2998970	995154	54600	5032710	21477978	0
17	1967972	8119930	2591220	107640	12786762	12615443	1108484
18	1197896	4036110	1287846	24180	6546032	19429132	535524
19	2224664	9499490	3009815	101400	14835369	10566597	1108723
20	983986	3486990	1109518	25740	5606234	20154342	750113
21	2139100	9027330	2884987	95940	14147357	11291807	1071524
22	1411806	4883060	1548555	28860	7872281	18105496	532912
23	2481356	10558470	3346314	78000	16464140	9242960	803588
24	1796844	7296770	2431077	67860	11592551	14825992	92146

Coalition	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
25	2823612	12431380	3983875	120900	19359767	5963456	1187465
26	2053536	8474180	2748378	66300	13342394	12777145	391149
27	2994740	13614770	4287888	109980	21007378	3914610	1588701
28	1925190	7852780	2549690	59280	12386940	13502355	621393
29	2866394	12897950	4065100	127140	19956584	4639820	1914284
30	2096318	8894340	2820583	73320	13884561	11453509	1172619
31	2994740	13707460	4230945	129480	21062625	2590974	2857090
32	470602	1575990	535802	8580	2590974	23919715	0
33	1582934	7074080	2329080	81120	11067214	15057179	386295
34	727294	2819050	935557	12480	4494381	21870868	145439
35	1754062	7781800	2486532	138060	12160454	13008333	1341901
36	684512	2324010	777839	16380	3802741	22596078	111869
37	1668498	7522450	2429588	212160	11832696	13733543	944449
38	983986	3687450	1226430	21060	5918926	20547232	44530
39	2053536	9078940	2944266	70980	14147722	11684697	678270
40	1283460	5468190	1791631	32760	8576041	17267728	666919
41	2353010	10706930	3412169	125580	16597689	8405193	1507807
42	1411806	6151340	1928577	34320	9526043	15218882	1765763
43	2566920	11855610	3708749	119340	18250619	6356346	1903723
44	1540152	6540950	2148966	34320	10264388	15944092	302208
45	2566920	11737830	3732912	95160	18132822	7081556	1296310
46	1711280	7454850	2385139	40560	11591829	13895245	1023614
47	2866394	13177450	4100405	180180	20324429	3372483	2813776
48	1283460	4400890	1427530	26520	7138400	18887005	485283
49	2096318	9360260	2944288	115440	14516306	10024470	1969913
50	1411806	5485870	1732025	34320	8664021	16838158	1008509
51	2438574	11344060	3510870	134160	17427664	6356346	2726678
52	1369024	5011110	1591879	31980	8003993	17563369	943327
53	2224664	10147930	3154267	132600	15659461	8700833	2150395
54	1540152	6126510	1905068	48360	9620090	15514522	1376076
55	2524138	11486020	3552666	99840	17662664	6651987	2196038
56	2010754	8433750	2719261	52260	13216025	12235018	1059645
57	3037522	13862810	4373608	106080	21380020	3372483	1758185
58	2438574	10239840	3317072	50700	16046186	10186172	278330
59	3208650	14841840	4589326	106080	22745896	1323636	2441156
60	2267446	9614670	3108089	47580	15037785	10911382	561521
61	3123086	14251510	4438387	92040	21905023	2048847	2556819
62	2353010	10211240	3182110	56160	15802520	8862535	1845633
63	3037522	14415180	4308415	163020	21924137	0	4586552

Results per coalition (AGV, Scenario 1)

Coalition	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
1	2220000	0	1810325	297180	4327505	17648153	4535030
2	888000	0	372483	4680	1265163	24461842	783684
3	2738000	0	2197515	199680	5135195	15599306	5776187
4	592000	0	238950	3120	834070	25187052	489566
5	2442000	0	2031301	163800	4637101	16324517	5549071
6	962000	0	600555	9360	1571915	23138205	1800568
7	2886000	0	2341197	171600	5398797	14275670	6836221
8	1850000	0	1399297	28860	3278157	19858702	3373830
9	3552000	0	2982043	144300	6678343	10996166	8836179
10	2146000	0	1682242	28080	3856322	17809855	4844512
11	4070000	0	3429895	86580	7586475	8947320	9976893
12	1998000	0	1563346	26520	3587866	18535065	4387757
13	3922000	0	3262619	109980	7294599	9672530	9543559
14	2590000	0	1946901	28860	4565761	16486219	5458709
15	4366000	0	3626159	77220	8069379	7623683	10817626
16	1702000	0	995154	54600	2751754	21477978	2280956
17	3404000	0	2591220	107640	6102860	12615443	7792386
18	2072000	0	1287846	24180	3384026	19429132	3697530
19	3848000	0	3009815	101400	6959215	10566597	8984877
20	1702000	0	1109518	25740	2837258	20154342	3519089
21	3700000	0	2884987	95940	6680927	11291807	8537954
22	2442000	0	1548555	28860	4019415	18105496	4385778
23	4292000	0	3346314	78000	7716314	9242960	9551414
24	3108000	0	2431077	67860	5606937	14825992	6077760
25	4884000	0	3983875	120900	8988775	5963456	11558457
26	3552000	0	2748378	66300	6366678	12777145	7366865
27	5180000	0	4287888	109980	9577868	3914610	13018211
28	3330000	0	2549690	59280	5938970	13502355	7069363
29	4958000	0	4065100	127140	9150240	4639820	12720628
30	3626000	0	2820583	73320	6519903	11453509	8537277
31	5180000	0	4230945	129480	9540425	2590974	14379290
32	814000	0	535802	8580	1358382	23919715	1232592
33	2738000	0	2329080	81120	5148200	15057179	6305309
34	1258000	0	935557	12480	2206037	21870868	2433783
35	3034000	0	2486532	138060	5658592	13008333	7843763
36	1184000	0	777839	16380	1978219	22596078	1936391
37	2886000	0	2429588	212160	5527748	13733543	7249397
38	1702000	0	1226430	21060	2949490	20547232	3013966
39	3552000	0	2944266	70980	6567246	11684697	8258746
40	2220000	0	1791631	32760	4044391	17267728	5198569

Coalition	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
41	4070000	0	3412169	125580	7607749	8405193	10497747
42	2442000	0	1928577	34320	4404897	15218882	6886909
43	4440000	0	3708749	119340	8268089	6356346	11886253
44	2664000	0	2148966	34320	4847286	15944092	5719310
45	4440000	0	3732912	95160	8268072	7081556	11161060
46	2960000	0	2385139	40560	5385699	13895245	7229744
47	4958000	0	4100405	180180	9238585	3372483	13899620
48	2220000	0	1427530	26520	3674050	18887005	3949633
49	3626000	0	2944288	115440	6685728	10024470	9800491
50	2442000	0	1732025	34320	4208345	16838158	5464185
51	4218000	0	3510870	134160	7863030	6356346	12291312
52	2368000	0	1591879	31980	3991859	17563369	4955461
53	3848000	0	3154267	132600	7134867	8700833	10674989
54	2664000	0	1905068	48360	4617428	15514522	6378738
55	4366000	0	3552666	99840	8018506	6651987	11840196
56	3478000	0	2719261	52260	6249521	12235018	8026149
57	5254000	0	4373608	106080	9733688	3372483	13404517
58	4218000	0	3317072	50700	7585772	10186172	8738744
59	5550000	0	4589326	106080	10245406	1323636	14941646
60	3922000	0	3108089	47580	7077669	10911382	8521637
61	5402000	0	4438387	92040	9932427	2048847	14529415
62	4070000	0	3182110	56160	7308270	8862535	10339883
63	5254000	0	4308415	163020	9725435	0	16785254

Results per coalition (MTS, Scenario 1)

	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
1	1837500	4152850	1271878	216840	7479068	17648153	1383468
2	441000	973440	288506	50700	1753646	24461842	295200
3	2058000	5089500	1499222	331500	8978222	15599306	1933160
4	367500	535730	158496	32760	1094486	25187052	229150
5	1984500	4746950	1430785	309660	8471895	16324517	1714277
6	661500	1572350	449389	90480	2773719	23138205	598764
7	2278500	5734170	1668063	674700	10355433	14275670	1879585
8	1323000	3099720	957932	224640	5605292	19858702	1046695
9	2940000	7205510	2109005	1599780	13854295	10996166	1660227
10	1690500	4212910	1262212	449280	7614902	17809855	1085932
11	3234000	8084960	2308394	1258920	14886274	8947320	2677094
12	1543500	3873870	1173982	764400	7355752	18535065	619871
13	3160500	7858760	2278630	1534260	14832150	9672530	2006009
14	1984500	4989920	1483098	1049880	9507398	16486219	517072
15	3454500	8750690	2472553	1196520	15874263	7623683	3012742
16	1470000	2323620	691183	131820	4616623	21477978	416087
17	2866500	6401720	1863968	481260	11613448	12615443	2281797
18	1470000	3294070	943455	1114620	6822145	19429132	259412
19	3013500	7350850	2093003	981240	13438593	10566597	2505499
20	1470000	2917200	848281	241800	5477281	20154342	879065
21	2940000	6937970	1996275	546780	12421025	11291807	2797856
22	1617000	3852810	1073834	415740	6959384	18105496	1445809
23	3160500	7872020	2203535	874380	14110435	9242960	3157293
24	2719500	5639530	1666472	475020	10500522	14825992	1184175
25	4116000	9517820	2690979	1553760	17878559	5963456	2668673
26	2940000	6762600	1961369	1750320	13414289	12777145	319255
27	4410000	10688210	2980323	1776840	19855373	3914610	2740705
28	2646000	6194240	1794640	507000	11141880	13502355	1866453
29	4189500	10120370	2833563	1294800	18438233	4639820	3432636
30	3013500	7288450	2082261	1437540	13821751	11453509	1235429
31	4483500	11036350	3040824	1143480	19704154	2590974	4215561
32	735000	996710	298984	104520	2135214	23919715	455760
33	2131500	5269940	1571437	384540	9357417	15057179	2096092
34	955500	2163850	642203	255060	4016613	21870868	623207
35	2499000	6282640	1819176	1128660	11729476	13008333	1772879
36	955500	1547390	450292	120900	3074082	22596078	840528
37	2425500	6002620	1770575	531960	10730655	13733543	2046491
38	1249500	2799550	816527	275340	5140917	20547232	822539
39	2866500	7137910	2061349	1568580	13634339	11684697	1191653
40	1543500	4028830	1174912	418860	7166102	17267728	2076858

Coalition	Fixcost	Wage cost	Fuel cost	Penalty cost	Total (coalition)	Total (non coalition)	Payoff
41	3307500	8321170	2395454	1282320	15306444	8405193	2799051
42	1984500	5168800	1483470	871260	9508030	15218882	1783776
43	3748500	9266140	2606237	1017120	16637997	6356346	3516345
44	1911000	4868370	1418691	506220	8704281	15944092	1862315
45	3675000	9038640	2591141	1081860	16386641	7081556	3042491
46	2352000	5961540	1725900	743340	10782780	13895245	1832663
47	3969000	9997390	2784637	1165320	17916347	5032710	3561631
48	1543500	3410680	977488	460980	6392648	18887005	1231035
49	3013500	7395180	2110118	581880	13100678	10024470	3385540
50	1837500	4344860	1210014	739440	8131814	16838158	1540716
51	3307500	8304140	2308361	992940	14912941	7975623	3622124
52	1764000	4049760	1149377	930540	7893677	17563369	1053643
53	3234000	7926230	2230352	709800	14100382	8700833	3709474
54	2131500	4946110	1369715	662220	9109545	15514522	1886621
55	3454500	8922810	2454929	828360	15660599	6651987	4198103
56	2719500	6620380	1894181	540540	11774601	12235018	2501069
57	4189500	10481640	2913538	1384500	18969178	3372483	4169028
58	3087000	7680270	2165539	1261260	14194069	10186172	2130447
59	4557000	11438960	3122892	1106040	20224892	1323636	4962160
60	3013500	7416500	2107154	1011660	13548814	10911382	2050492
61	4483500	11168040	3078003	1191060	19920603	2048847	4541239
62	3307500	8324550	2338742	885300	14856092	8862535	2792061
63	4777500	12103390	3290161	1255800	21426851	0	5083837