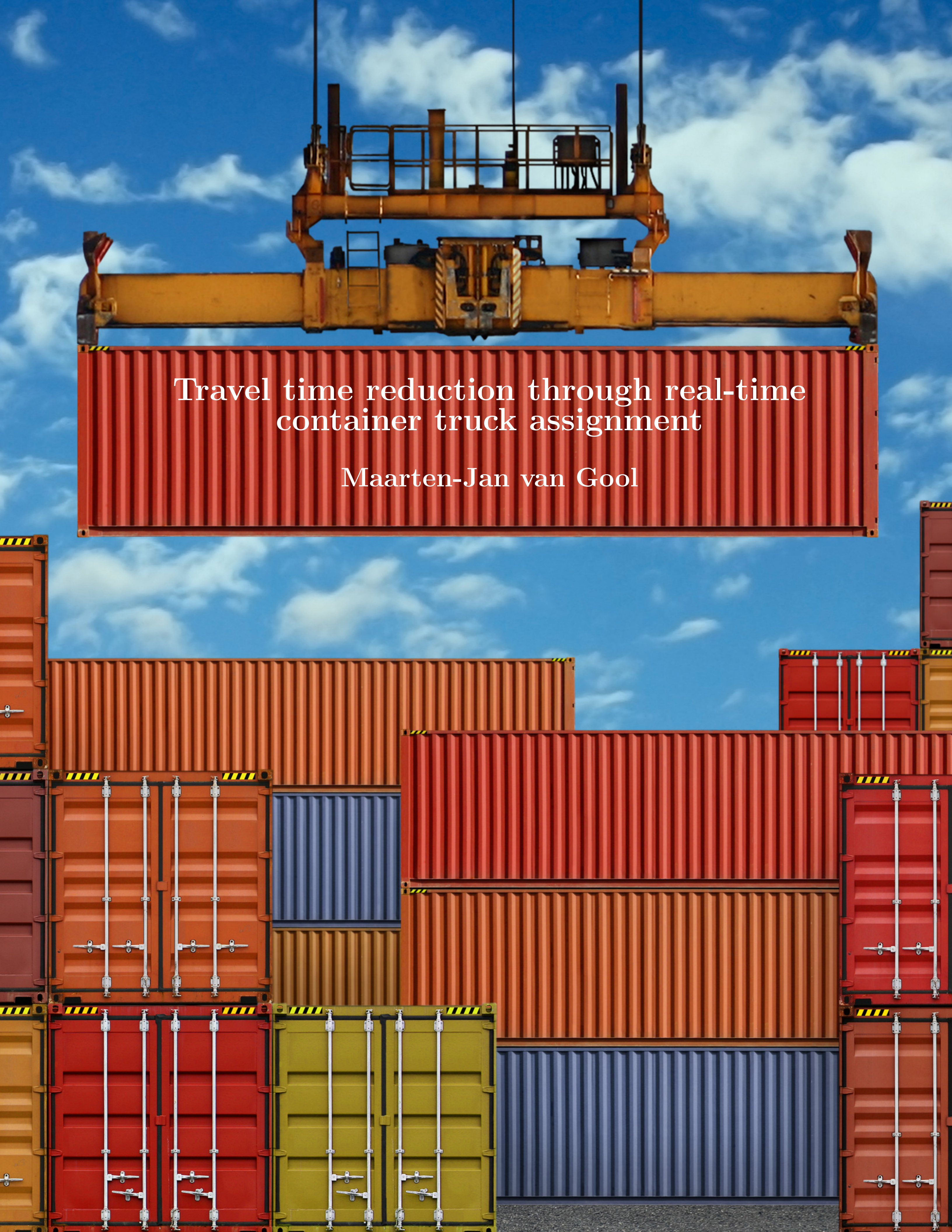

Travel time reduction through real-time container truck assignment

Maarten-Jan van Gool

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Master Thesis

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Abstract

Truck container transport from and to terminals in the port of Rotterdam is far from optimal. This is caused by a lack of communication and thus a lack of (reliable) information. On top of that, the different parties involved have different priorities.

In this research the goal was to build a Multi-Agent truck time slotting proof of concept for terminals in the port of Rotterdam in order to demonstrate the use of information sharing for decreasing the total travel time.

Based on literature and field research, we came up with two potential improvements which would decrease travel time of trucks, without having a significant impact on the structure in the port as a whole (which makes the solutions easier to implement). We tested these suggested improvements in simulation.

The first improvement deals with the sharing of information with regard to arrival and travel times, which are represented in waiting profiles. By sharing this information, transport companies are enabled to decrease their travel times by making better decisions.

The second improvement involved the 'loosening' of the truck-container coupling. When a truck is ordered to pick up a container it may be a time-saving move, because of changed circumstances, to pick up another container than initially intended. Implementing this possibility unfortunately did not decrease the travel times. This is explainable due to limitations of the simulation.

The results show some promise with regard to improvements without significant changes to the current situation. More research to investigate and confirm these improvements and investigation of next steps toward implementation are required.

Chapter 1

Introduction

The Netherlands is considered to be an important trading nation. This is because of the size of the ports of Zeeland Seaports, Amsterdam, and especially Rotterdam. The construction of Maasvlakte 2 in Rotterdam will allow the newest generation of large sea ships to enter the port. The construction of Maasvlakte 2 will also solidify the position of Rotterdam port as the largest port in Europe (van den Broek et al., 2010; Europe Container Terminals, 2011; Kolkman, 2009).

Sea ships dock at the port of Rotterdam every day, bringing in up to 15.000 containers each. When a ship arrives at the port, it will move on to its designated terminal. At this terminal, the appointed containers will be loaded or unloaded. The container is picked up by a crane, and dropped upon an automatic guided vehicle (a.g.v.). The a.g.v. will transport the container to one of the stacks of the terminal. The sea-side stack crane will lift the container from the a.g.v., and put the container on the stack.

On average, in a week a truck will arrive at the terminal to pick up the container (Connekt, 2003; Rodrigue & Notteboom, 2009). The land-side crane of the stack will, when the vehicle is in position, put the container on the trailer. Subsequently, the truck will continue the containers' journey to the end-customer. At the destination, the container will be emptied. The empty container will be returned to the terminal and the truck will be ready for its next order.

This is a description of just one of the (import) transport cycles. In total, ±410 million tons of cargo are transferred through the port each year (measure from 2009). The expected growth by 2020 is 25%. Of all this cargo, 56% is transported on the road.

One of the goals of the Port Authorities is to decrease road transport with 37,5% (in total) by 2035, and increase barge and train transport. Extrapolating these numbers of transference growth and decreased road transport, effectively this means the absolute number of trucks on the road will increase (van den Broek et al., 2010). Traffic jams already cause a loss of 800 million euro a year for the Dutch transport sector.

Traffic jams have a huge impact on Dutch road traffic in general. There are however several issues specifically regarding the transport sector. Because many (often competing) parties are involved in transferring and transporting goods it is difficult to achieve a high level of efficiency within transport. There is a serious lack of coordination between different parties (e.g. van den Broek et al. 2010). For example: When a truck has an order to pick up a container from the terminal, the terminal will not be notified before the truck arrives at the terminal gate. The terminal is effectively blind as to who will arrive when.

These huge costs of delays cause parties from inside and outside the transport sector to seek solutions. For example, several parties started innovative projects which resulted in Portbase (Portbase, 2011) and RITS (Reistijdverwachting In Transport Management Systemen; *English:* Travel time expectations in transport management systems) (Verkeersonderneming, 2010b). Portbase is a company concentrated on gathering and exchanging information, while RITS is a project related to arrival time estimation, both based on real time and historical data.

The research performed in this thesis is related to an initiative set up by Logica, TLN (Transport en Logistiek Nederland; *English:* Transport and Logistics Netherlands) and TNO (Toegepast Natuurwetenschappelijk Onderzoek; *English:* Applied Scientific Research). These organizations joined forces in a project specifically related to road container transport from and to the port of Rotterdam. The goal is to build a system for trucks at a terminal in order to decrease waiting times (see appendix A.2).

In section 1.1 the goals of this research will be discussed and these goals will be formalized in section 1.2. This will be followed up by stating the research questions in section 1.3. This chapter will be concluded with an outline of the methodology (section 1.4), and a detailed explanation of the structure of the paper (section 1.5).

1.1 Goals

Delays, like waiting time (in front of and) at terminals and traffic jams cause transport to be late. The *waiting time* is defined in this thesis as all the added delays in a whole transport cycle. The travel time of a trip is defined as the time a trip takes from beginning to end. The goal of this research is as follows:

> *Build a Multi-Agent truck time slotting proof of concept for terminals in the port of Rotterdam in order to demonstrate the use of information sharing for decreasing the total travel time.*

Based on preliminary research done for the project proposal, the decision was made to research a multi-agent based solution. A multi-agent system is a system in which control is distributed over several autonomously operating entities (agents) with each their own goals. Control in the current situation is distributed: there is no central controller. Our estimation is that introduction of a central controller is unfeasible because this would require a large change in the current power balance.

A second issue is the lack of willingness of terminals and transport companies to hand over control of (sensitive) company information. Literature also shows some promising results with multi-agent systems in this respect as well (e.g. Douma 2008; Moonen 2009). Chapter 2 will elaborate on this design choice.

We chose to build a proof of concept because, given the available resources, an actual implementation is unfeasible. Information sharing was chosen as a method of decreasing the total travel time specifically because literature suggests that a lack of adequate communication is currently one of the bigger problems (see e.g. appendix A.5).

Important to note here is that practical considerations are more important than the theoretical optimization questions. Optimization by itself is not the goal. This research is intended as a step towards implementation. The roles, intentions, behaviors and reservations of the different parties involved (terminals, TLN, port authority, transport companies, et cetera) play an important role in the design choices. It may very well be that the best (theoretically) possible solution is not one implementable in practice. In this research, implementability is a requirement.

In order to increase information sharing regarding the waiting and travel times of trucks, more than only the cooperation of truck companies is required. Currently, the transport company is caught in between the requirements of the terminal and the customer. The terminals have a powerful position within the logistic chain because of its control over the flow of goods on the terminal. Therefore, in order to improve the current situation, the interests of the terminal cannot be ignored. In order to be able to facilitate trucks, we need to facilitate the terminal. Generating wide support for the multi-agent solution is another one of the requirements to achieve the goal. Without both terminal and truck company support, nothing will change.

The goal is to decrease the overall waiting time. However, as stated in the goal, the goal is restricted to information sharing regarding arrival and travel times specifically. In the next section the term 'travel time' will be formalized. In section 1.3, the research questions will be specified.

1.2 Formalizing travel time

During the day, a truck executes several orders. For example, a truck is ordered to pick up a container at the Euromax terminal, and to deliver this container at a customer in Breda. The route the truck has to follow (also displayed in figure 1) will be the following:

A The truck will start from the place where the truck is located, e.g. from the head office of Post Kogeko (a transport company).

B It will pick up a container at the Euromax terminal.

C It will continue on its way towards the customer, in Breda, to deliver the goods.

D After the goods are delivered, it has to turn in the empty container. In this case, this job can be combined with the next order, which is to pick up a container at the Europoort Terminal.

E At the end of the day, it will deliver contents of the container picked up at the Europoort at the customer in Delft.

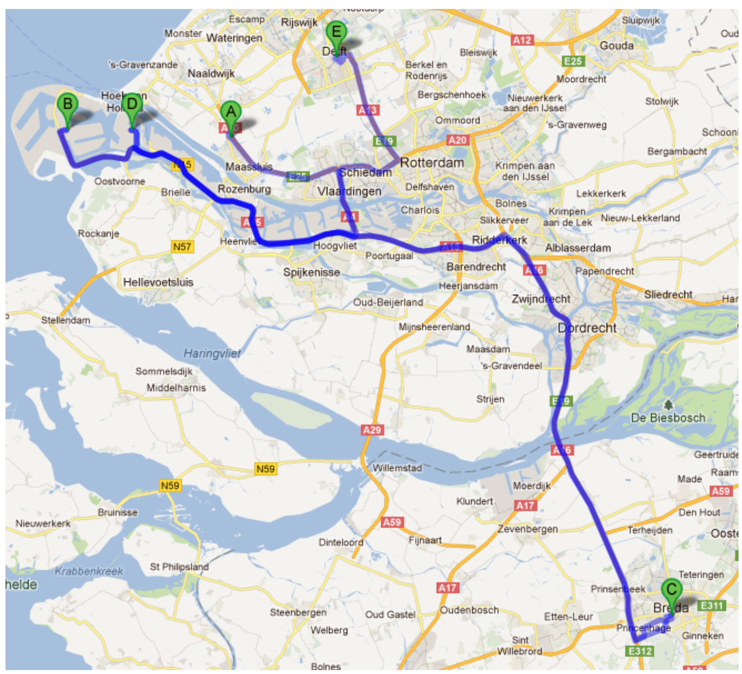

Figure 1: Two trips a truck may take (made with Google Maps (Google, 2012)).

The route the truck has to follow consists of two orders which each can be split up in several parts: for example, one recurring part is the time of the truck on the road. Another part is the waiting time at the terminal, or at the customer. Figure 2 gives an overview of the different parts within one order. In this thesis the fulfillment of an order, from start to finish, is defined as a *transport cycle*. The time this takes is defined as the *travel time*.

Given these different parts, the Trip Travel Time can formally be defined as:

$$TTT_j = TPT_j + TWT_j \tag{1.1}$$[1]

Because of the varying waiting times (TWT_j), as opposed to relatively stable process time (TPT_j), a distinction is made between these two. The Trip Process Time is defined as follows:

$$TPT_j = \sum_{i=1}^{3}(R_{i,j}) + LT_T + LT_C + LT_D \tag{1.2}$$

Moving from A to B, from B to C and from C to D is defined as road time: R_i. The terminal loading time LT_T represents the time it takes to load a truck with a container at the terminal. In our example this is at point B. LT_C and LT_D represent the load/unloading time at the customer and depot respectively, which are at point C and D in our example.

The durations for different parts of the trip are influenced in different ways. Road time, for example, can be longer because of traffic jams. It can be busy at the terminal, so the terminal waiting time can be high. The Trip Waiting Time (TWT_j), is defined as follows:

$$\begin{aligned} TWT_j = \textstyle\sum_{i=1}^{3}(T_{i,j}) + WP(T_{WP}, ETAT_j) + WP(S_{WP}, ETAS_j) + \\ WP(C_{WP}, ETAC_j) + WP(D_{WP}, ETAD_j) \end{aligned} \tag{1.3}$$

The formulas and examples described above are formalizations and examples for a truck picking up a container at the terminal. Besides this transport cycle, there is a second cycle, in which the truck has to deliver a container at the terminal. Both of these cycles are displayed in figure 3. The formula with regard to the second cycle is:

$$\begin{aligned} TWT_j = \textstyle\sum_{i=1}^{3}(T_{i,j}) + WP(T_{WP}, ETAT_j) + WP(S_{WP}, ETAS_j) + \\ WP(C_{WP}, ETAC_j) \end{aligned} \tag{1.4}$$

Because the "delivery-of-a-container-at-the-terminal problem" is almost the same as the "picking-up-a-container-at-the-terminal problem", throughout the thesis, a distinction between these two processes only is made when relevant.

The durations of the different parts of the trip are influenced by their *waiting profile* (*WP*). The waiting profiles record the variable waiting time. Now, given

[1] The legend for all symbols in the formulas is presented in table 1.

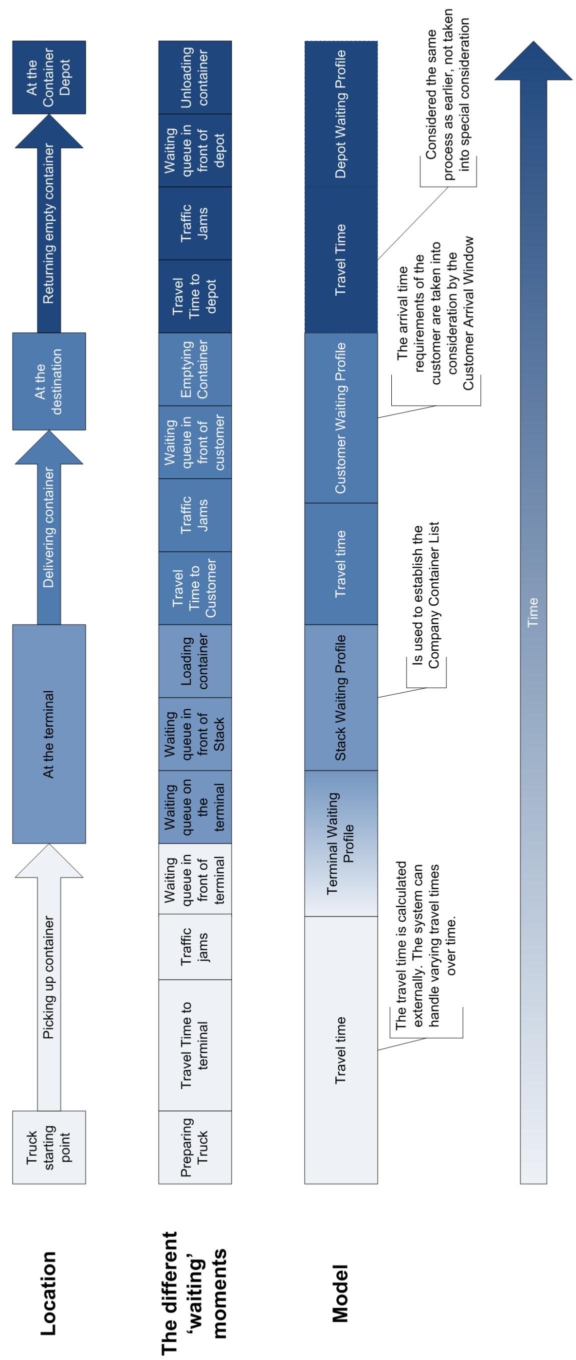

Figure 2: Truck container transport timeline.

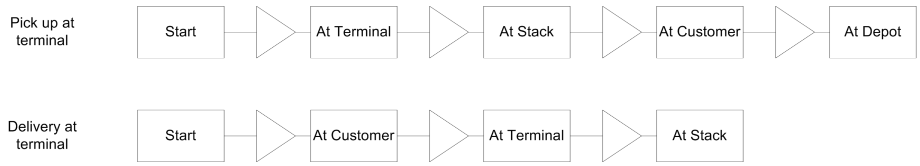

Figure 3: Both transport cycles.

the total waiting time per trip, the total waiting time per transport company (CWT_k) is:

$$CWT_k = \sum_{j=1}^{n(k)} (TWT_{j,k}) \tag{1.5}$$

With n as the number of trips and m as the number of transport companies, the goal of this research is to:

$$min(\sum_{k=1}^{m} \sum_{j=1}^{n(k)} (TWT_{j,k})) \tag{1.6}$$

TTT_j	=	Trip Travel Time for trip j
TPT_j	=	Trip Process Time for trip j
$TWT_{j(,k)}$	=	Trip Waiting Time for trip j (and transport company k)
$R_{i,j}$	=	Road Time of part i for trip j
LT_T	=	Load/unloading time at terminal i.e. the (standard) time it takes to load/unload a container
LT_C	=	Load/unloading time at customer
LT_D	=	Load/unloading time at the Depot
$WP(...)$	=	Waiting Profile
$T_{i,j}$	=	Traffic delay of part i for trip j
T_{WP}	=	Terminal Waiting Profile
$ETAT_j$	=	(Estimated) Time Of Arrival at Terminal for truck of trip j
S_{WP}	=	Stack Waiting Profile
$ETAS_j$	=	(Estimated) Time Of Arrival at Stack for truck of trip j
C_{WP}	=	Customer Waiting Profile
$ETAC_j$	=	(Estimated) Time Of Arrival at Customer for truck of trip j
D_{WP}	=	Depot Waiting Profile
$ETAD_j$	=	(Estimated) Time Of Arrival at Depot for truck of trip j
CWT_k	=	Total Waiting Time for transport company k

Table 1: Legend.

1.3 Research questions

Based on the goal stated in section 1.1, the following research questions were formed. The primary research question in this thesis is:

> *How can information sharing regarding expected waiting times help in actually decreasing waiting times?*

There are several subquestions that are intended to answer different parts of the main research question. These can be found in table 2. Different means of testing are used to answer these subquestions, namely literature study, field study and simulation. In the next section these methods will be explained.

Research Questions:	Means of testing: Lit. study	Field study	Sim.	Ch.
RQ1. Are multi-agent systems applicable to the situation in the port of Rotterdam?	√	√	√	2, 3, 5
RQ2. What can be learned from earlier MAS implementations?	√			2
RQ3. What are the current problems in truck transport?		√		3
RQ4. Which party can facilitate further steps in the implementation process?		√		3
RQ5. What kind of agent system in what form would fit container transport in its current form?			√	4
RQ6. Do the suggested improvements actually decrease waiting time?			√	5

Table 2: Research subquestions, their means of testing (literature study, field study or simulation) and the chapter in which these questions are answered.

At the end of each respective chapter, we will attempt to answer each of these research subquestions. In our conclusion (chapter 6), we will review all our answers to the subquestions in relation to the research project as a whole and we will attempt to answer the main research question.

1.4 Methodology

Design science was chosen as the research method: designing and consequently building a system (the simulation) fits with our main goal. Evaluating the built artifact will answer the main research question. The subquestions, as displayed in table 2, are to guide the design process to an answer of the main research question.

Nunamaker et al. (1991) propose a 5 step design science process. Figure 4 shows the design science cycle. A heavy emphasis is placed on constructing the conceptual framework. In this research, the fifth step (evaluation) will be taken twice: We will start by evaluating earlier built systems and we will end by evaluating our own system.

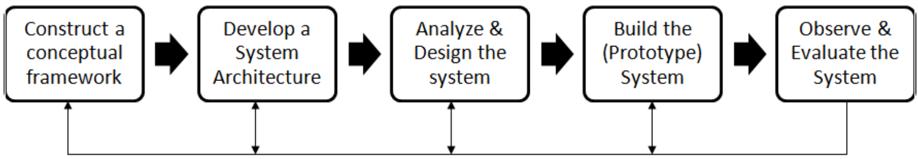

Figure 4: The design cycle.

The research in this paper is split up in three parts. In the next subsections the methodology regarding these three different parts of the study and how these relate to design science will be explained.

1.4.1 Literature research

The main research question is about sharing of information regarding waiting profiles. The design goal states that a multi-agent system should be built. The underlying assumption here is that a distributed (multi-agent) solution is preferable to a more centralized approach. The first part of the literature review attempts to justify this assumption. The literature was searched for reasons to, and reasons not to use a multi-agent system.

Based on the conclusion that the use of a multi-agent system for our problem is viable, the next step in the literature research was to find examples of multi-agent systems. The literature was searched for multi-agent systems that are comparable to the case studied. These multi-agent systems were analyzed with regard to their implementation status (simulation or practical tests) and noteworthy results were reported. Furthermore, we take a brief look at infrastructural solutions for comparison.

1.4.2 Field research

In order to increase the chances that the research performed is relevant to the transport sector, a field study was conducted. Besides exploring the workings of the sector, the goal was to figure out what the specific problems within the sector are, and what possible solutions may solve these problems. The second goal was to look at actual implementation: which party can move this project from theory into practice?

The field study consists of several informal interviews with different parties in the sector. Participants were questioned on the current problems and possible solutions in the sector. Furthermore, feedback was gained on several ideas we had regarding possible solutions.

The literature and field study relate mostly to the construction of a conceptual framework. These studies also lay the basis for the system architecture.

1.4.3 Simulation

The bulk of the design science steps are related to building the artifact. In the third part of this research project a multi-agent truck time slotting proof of concept is designed and built. Based on the literature and field research, functionalities were formulated and consequently implemented.

In chapter 4, we discuss the development of the system architecture. In section 5.1 we design the system. Consequently, the system is built. In section 5.7 the results of the simulations are discussed. In section 6, we evaluate the results from the simulation and the built system.

1.5 Structure

In figure 5 the structure of this thesis is laid out. As explained in the previous section, the research consists of three parts. Chapter 2 will introduce multi-agent systems and will discuss their use. We will consequently take a look at some earlier implementations of multi-agent and other solutions.

The field research done is described in chapter 3. The different parties involved in container transport will be discussed in this chapter. The literature and field research will lead towards the simulation part of the research. Chapter 4 will combine the insights from literature and the field to make several design decisions regarding the prototype. Chapter 5 will discuss the implementation of the simulation, and the results obtained.

In the conclusion, chapter 6, the results from the simulation will be related back to the field research. An evaluation of the built simulation will be performed as well.

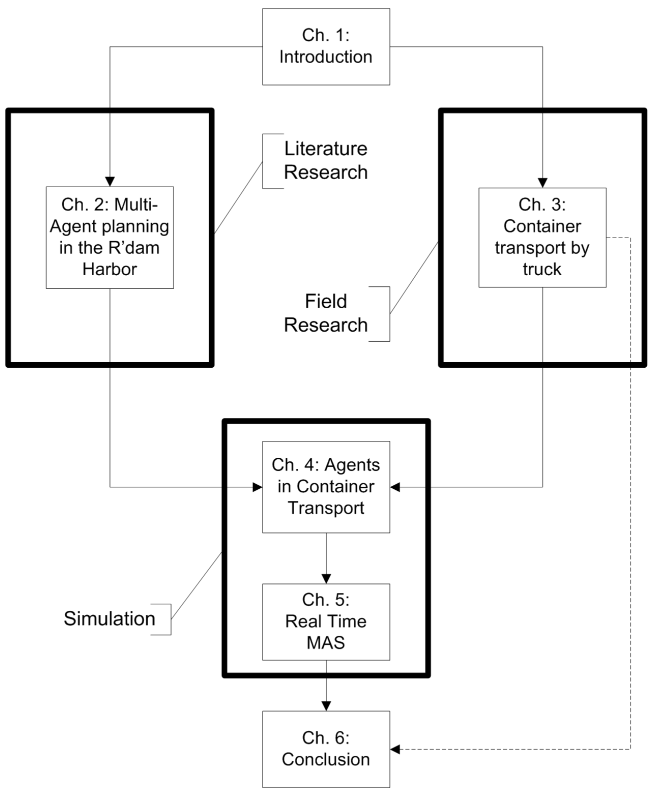

Figure 5: The chapters in this thesis, their relation, and the different parts of research.

Chapter 2

Multi-agent planning in the port of Rotterdam

This chapter will introduce multi-agent systems to truck transport on and around terminals in the port of Rotterdam. We will start out by introducing agent, multi-agent systems and multi-agent planning (section 2.1). In this section, we will investigate the literature for reasons to apply multi-agent systems to the situation in the port of Rotterdam as well.

The research question to be answered in the first part of this chapter is the following:

RQ1. *Are multi-agent systems applicable to the situation in the port of Rotterdam?*

The second part of this chapter will review several earlier suggested (multi-agent) improvements for scheduling and/ or congestion issues (section 2.2). Consequently, the practical applicability of multi-agent systems will be discussed (section 2.3). The research question to be answered in this part of the chapter is the following:

RQ2. *What can be learned from earlier MAS implementations?*

In order to get a complete picture of the possible solutions, several other suggestions for improving the congestion issues in the port will be discussed in section 2.4. In the conclusion of this chapter (section 2.5), we will relate these other possibilities to the choice of multi-agent systems, and we will answer the research questions.

2.1 Are multi-agent systems applicable to the port of Rotterdam?

In this section, we will investigate whether or not multi-agent systems are applicable to the problems in the port of Rotterdam as introduced in chapter 1. This section will first define and explain multi-agent systems and multi-agent planning in general (subsection 2.1.1). In subsection 2.1.2 the requirements for a MAS application will be related to the truck scheduling problem.

2.1.1 Multi-agent planning

Within the field of artificial intelligence, planning is an important research area. In order to solve problems, individuals can make a deterministic step-by-step plan in order to solve their problem. In more complex environments, plans need (on-the-fly) adaption to unexpectedly changing environments. In order to be able to operate within an environment, one should be prepared for whatever the environment entails. In this sense, in order to operate in an environment, making some sort of an (adaptable) plan[1] is always required.

Unfortunately, there is not a generally accepted definition for what exactly an agent is (M. Wooldridge & Jennings, 1995; Franklin & Graesser, 1997). M. J. Wooldridge (2002) uses the following definition: *"An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives."* (p. 15). Russell & Norvig (2003) would describe an agent as: *"An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators."* (p. 32). In this thesis both of these definitions would apply.

An agent has certain goals and makes an attempt to achieve these goals. It operates in an environment autonomously: an agent makes its own decisions. Making plans, adapting to unexpected changes and learning from mistakes can be important parts of agent systems. Obviously, agents hardly ever work in a vacuum. Other agents may inhabit their environment as well. An environment with multiple agents is called a multi-agent system (MAS).

Depending on the situation, agents could be competing, working together or a combination of working together and competing. As long as the MAS is not a zero-sum game, making plans in multi-agent systems is considered to be coordination between different agents (de Weerdt et al., 2005). Agents have to work together to achieve a common goal or need each other to achieve their individual goals.

[1] According to the more common definition, reactivity is usually defined as the opposite of a plan. However, reactivity does prepare for an uncertain environment. In the definition used here, a 'plan' is defined as simply being prepared for an environment. This definition would include reactiveness.

Communication can play a big role in multi-agent coordination of making plans. In order to be capable of reasoning with not yet fully developed plans, "assertions" can be used (Brenner & Nebel, 2009): the details will be filled in when the preconditions are satisfied. One requirement of asserting not yet fully developed plans is that there is no (or at least a very slim) chance of the details disrupting the global plan. Assertions can be refined until subtasks remain that are performable by individual agents. At this point, individual agents can plan and coordinate their own subtasks for themselves (de Weerdt et al., 2005).

Coordination between agents can be explicit or implicit (de Weerdt et al., 2005). With explicit coordination, agents directly communicate with each other to decide on a course of action. With implicit coordination, invididual agents act according to "local rules": given situation x, perform y. These rules are specified to streamline coordination. Explicit coordination is usually more precise and predictable.

Paulussen et al. (2003) (discussed in detail in section 2.2.1) is an example of explicit coordination. Implicit coordination is usually less time consuming and more practical in a dynamical environment. Valckenaers et al. (2002) (discussed in detail in section 2.2.2) propose such a system for manufacturing control.

Another way to make coordinating more efficient is open-ended planning. Instead of agents having to wait until a global agreement is reached, agents make their own plans and while executing try to combine their plans by finding common goals with the other agents (desJardins et al., 1999).

2.1.2 Why multi-agent planning?

When introducing multi-agent systems to solve planning issues, a relevant question to answer is why multi-agent systems should be used. There are multiple factors that can be reasons to use a multi-agent system for planning (M. J. Wooldridge, 2002; Jennings & Wooldridge, 1998):

- *The environment is open, flexible, complex and/or unpredictable:* In a highly complex and/or flexible environment (like the real world), ad hoc autonomous decision making is often required. Agents are intended to perform these tasks. The port of Rotterdam, with the amount of parties involved in container transport conforms to this requirement.

- *Information, control, resources and/or expertise is distributed:* When resources are distributed, there has to be a method for different parties to access these resources. Multi-agents are built to accomplish this. With different competing parties involved, competitors may not freely share delicate company information (also see Douma 2008) and therefore container transport also conforms to this requirement.

- *Agents are a natural metaphor:* Autonomously operating agents are not always software agents. People are agents as well. Describing organizations as a multi-agent system can be a good metaphor. Within container transport, this metaphor also applies. Therefore, an agent architecture also applies to this problem: tasks can be allocated to software as well as humans.

- *Legacy Systems:* Often "older" (software) systems are involved in parts of the workings of organizations. Adapting legacy systems with the purpose of for example integration can be really difficult. Using agents as an adapter to facilitate communication between systems can be valuable (also see Boer et al. 2003). Regarding container transport, this factor may be applicable. However, this factor is not within the scope of this thesis.

Related to the first factor, in order to solve difficult problems, multi-agents can be used to simplify the issue. Simple agents can work together to solve difficult problems.

Another way of looking at choosing between a centralized or a decentralized (multi-agent) solution, is to demonstrate the inappropriateness of a centralized approach. Marik & McFarlane (2005) list three possible characteristics that would make a centralized approach inappropriate and therefore an agent based solution attractive:

- A centralized solution's infeasibility: Only a part of the information required is available.

- A centralized solution's impracticality: Even if all the information is available, practical (time, cost and quality) considerations make a centralized solution inappropriate.

- A centralized solution's inadvisability: A centralized solution may be susceptible to disruptions and or reconfiguring the whole system to a centralized approach may be too costly or too complex.

We feel all three of these characteristics apply to container transport by truck: At any point in time, transport companies may only have a part of the information available, because other transport companies or terminals are not communicating or willing to communicate their trip information.

Even if every part of the system is willing to make their information available, the information may not be available on time. Because of time pressure, decisions based on imperfect and/or incomplete information have to be made.

The third characteristic may be the most relevant: it is simply too costly to reconfigure the whole system in the port. It is unlikely that terminals and transport companies are willing to listen to a central authority which not necessarily has their goals in mind. This characteristic is directly related to our goals as discussed in section 1.1: we intend to improve the situation without fundamentally changing it.

There is also literature that concludes MAS is relevant for the transport sector (Fischer et al., 1996; Davidsson et al., 2005). Fischer et al. identify four reasons why multi-agent systems are suitable for the transportation domain:

- The domain is inherently distributed.
- There is a high degree of dynamics in the process of planning.
- Centrally maintaining and processing of information is very complex.
- Cooperative processes exist in real transportation business. MAS are specifically suitable for local planning and negotiation among agents.

The problem in the port of Rotterdam conforms to the requirements for the application of multi-agent systems as set by Jennings & Wooldridge (1998). The characteristics as listed by Marik & McFarlane (2005) apply to truck container transport in the port. Furthermore, there are several reasons why multi-agent systems are applicable to the transportation domain (Fischer et al., 1996).

The literature suggests multi-agent systems are applicable to a distributed situation like the port of Rotterdam. Given the applicability of multi-agent systems to our problem, we will now investigate several earlier implementations of multi-agent systems. In chapter 3, the transport sector will be investigated in more detail. On the basis of the literature and field study combined, we should be able to answer the research question.

2.2 Multi-agent planning: Does it work?

Now that we concluded from literature that multi-agent systems are applicable to the transport sector, we will investigate several earlier attempts of solving planning problems with multi-agent systems.

2.2.1 Patient scheduling in hospitals

The first example of planning with multi-agent systems is dynamic patient scheduling in hospitals (Paulussen et al., 2003, 2006). In hospitals patients make use of the (limited) hospital resources. By implementing a multi-agent system, "patient-agents" can negotiate with "resource-agents" in order to divide the available resources over the patients. In this study, the health of the patient was quantified and used as a measure to prioritize patients.

The patient-agent requests a specific resource agent for a time slot. If the slot is available, the patient agent will get it. If the slot is taken, the question is forwarded to the agent occupying the slot. This agent will try to reschedule, and will charge the "health-cost" to the requesting agent. Based on the price, the requesting agent will make a decision.

According to the authors, this multi-agent system would significantly improve the current patient scheduling practice in hospitals. However, practical implementation is not yet achieved, and thus not evaluated. The authors believe the legacy systems already in place can be well encapsulated by agent systems.

Relevance

This purely theoretical research was evaluated by simulations. In these simulations the agent system performed consistently better than the "first come first serve" method. However, because test results are limited and stem from simulation only, the results carry less weight.

This research is relevant because a system which is capable of dynamical planning is demonstrated, and the results at least point towards it being a workable solution.

2.2.2 Multi-agent manufacturing control

Valckenaers et al. (2002) propose a multi-agent system for manufacturing control inspired by the workings of an ant colony. The intelligence of the system emerges from the application of local rules at the individual level.

The goal of the system is efficient transport within a manufacturing control system. Just like ants leave a pheromone trail to guide other ants to food, order agents propagate their forecasts on arrival time to the nodes they plan to cross. Similarly, node agents will back-propagate their load forecasts to nodes existing earlier in the chain.

Based on the local information at the node (expected load forecasts of upcoming nodes), the order agent can make a decision on which way to go next.

Just like the pheromones with ants, the propagated information "fades" from the nodes as time passes. An agent can make a different decision at any node, and propagate this new plan, while the old information fades.

By making information available locally (at nodes), agents can make local decisions based on local information. For example, if the 'left turn' has a high expected load, the 'right turn' may be favored. This makes decision making less difficult, because instead of having to consider the whole route, only a single choice on the route has to be considered. By using automatic evaporation, communication otherwise required is rendered obsolete.

Relevance

The multi-agent manufacturing control system suggests the use of implicit negotiation inspired by natural phenomena (ants). Instead of active communication with other agents, agents use the local information available to make decisions on their own. Unfortunately, the paper does not discuss any testing, the idea of using "ant-like" systems is only hypothesized.

2.2.3 Airport planning

Scheduling air traffic efficiently is a subject of study since the 1950s. In this subsection we will discuss some relevant papers. First off, it is widely recognized that finding optimal airport schedules is not achievable (yet) by calculating the mathematical optimum. Machine-only solutions simply do not have the capacity human experts have with regard to planning and their capability to cope with unforeseen consequences (Etschmaier & Mathaisel, 1985). According to other literature, combining human expertise with the computational power of machines is using 'the best of both worlds' (Beynon et al., 2002).

Dividing the planning over different teams, with different tasks, is a measure proposed to decrease the problem space. Diepen et al. (2007) for example split up the planning in two phases. In order to make a schedule for all the arriving and departing planes in the next 24 hours, the planes are first divided over several gate-plans. When all planes are divided and satisfactory plans are generated, the gate-plans are divided over the actual gates.

At Schiphol Airport the planning is divided over two planning teams: the first team plans the global schedule over two to four months, while the second team is responsible for the day to day planning (Bian et al., MISTA 2003). An important factor of airport planning is measuring the actual criteria on which to judge a schedule. A rather simple version would be to just measure the number of hours planes are grounded (Bian et al., MISTA 2003).

Jonker et al. (2007) propose a multi-agent system for arrival, gate and departure planning. The resources (time and number of gates) are limited: it is therefore difficult to make airport schedules for multiple competing parties. This raises concern: will parties act in a competitive or cooperative manner?

In order to stimulate cooperative behavior Jonker et al. suggest to implement a monetary system. When monetary means are limited, plane companies can earn money by helping others and can use that money in turn to buy help. However, this only works when reasonable prices are asked.

For example, if one plane plan needs rescheduling because of unforeseen circumstances, and other planes exploit this situation by asking a higher price than reasonable, the local utility of the exploiters will go up, but the global utility will go down.

Jonker et al. suggest collective retaliation at the exploiters by charging them higher prices as punishment. However, this introduces a third category of agents; the forsakers. Forsakers will just as other agents overcharge the exploiters, but just a bit less than the others, in order to win the bid.

The conclusion is that by using a monetary system like this, there always will be agents exploiting the system one way or another. Jonker et al. therefore suggest a monetary system with a 'memory'. The value of the money depends on the "hands" it went through. When trustworthy parties use the money, it will keep its value. However when exploiters spend it, the monetary value will decline. This solution would result in agents that really have to consider the trustworthiness of other agents before making a deal.

Relevance

Airport time slotting has been used in practice for years now (also see appendix A.3). The method of making a complete schedule for the long term and adaptation on the spot when required has proved to be successful. Fining the airlines for not making their slots seems to be the preferred method of enforcing this system.

Bian et al. show the use of this multi-phase planning. Making general plans first and filling in the details later seems relevant in changing environments, like truck transport.

However, when enforcement of the rules is required, exploitation of these rules is also possible. Furthermore (as will be explained in more detail in chapter 3.2), time slotting employed in air transport is not applicable to truck container transport because a third party (the customer) decides on the arrival of containers, not the transport company itself.

What Jonker et al. show is that explicit negotiation should be avoided because it complicates matters to an extent and it becomes very difficult to actually implement, while section 2.2.2 shows that without explicit negotiation an elegant solution can be achieved.

2.2.4 Time slotting for barges

Douma et al. (2008) (also see his Phd. thesis: Douma, 2008) did research on a multi-agent system for time slotting and scheduling situations regarding container barges in the port of Rotterdam. Barges enter the port, visit several terminals to turn over containers, and leave. Unfortunately, scheduling these visits is hard because the arrival time of barges in the port is not plannable and waiting times at terminals can vary (especially when the barge before you arrives late).

The implemented multi-agent system had two kinds of agents; terminal agents and barge agents. In order to make efficient planning possible, the terminals were able to provide the barges with their *waiting profile*. The waiting profile is a graph of the maximum waiting time for a barge at a terminal at the point of arrival at that terminal (see figure 6 for an example).

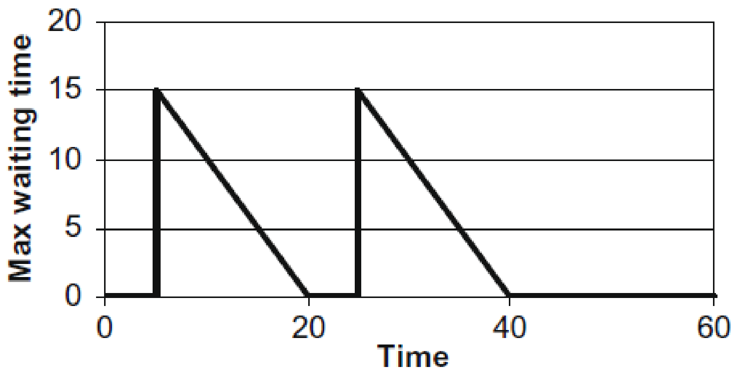

Figure 6: An example of a waiting profile (Douma et al., 2008). At Time 5 a barge enters the terminal, and at time 20, it leaves again. It would be best for a new barge to plan arrival between time 20 and 25 or after time 40.

The barge agent requests all waiting profiles of the terminals it has to visit. Using these waiting profiles, the agent is able to calculate the most efficient route. When this route is calculated, bookings are made, and the trip is carried out.

The model performed well in simulation. Freely sharing the waiting profiles resulted in a decrease of the average delay per barge by 80%, compared to the simulations in which no information was shared.

The main limitation to the system was its lack of flexibility. The system did not account for the possibility of barges arriving late. It was assumed barges always arrived on time to make their appointments.

Another limitation to actual implementation may be the unwillingness of terminals to keep their appointments: given figure 6, what would the terminal do if a third (unscheduled) barge arrives at time 20? Will it allow this barge to load and unload, delaying the barge scheduled at 25, or will it allow 5 minutes downtime and wait for that barge? And what if the barge of time 25 arrives at 35 instead?

Relevance

This research has (only) been tested in simulations, but still, completely sharing arrival time information (sharing the waiting profiles) seems to reduce the waiting times significantly. These results are indicative of the usefulness of waiting profiles.

Comparing truck transport to barge transport, their correspondence is limited by the same problems as mentioned in 2.2.3: an appointment system cannot work in truck transport because a third party is involved.

2.2.5 Road container transport I

Boer et al. 2003 (also see the report of Connekt, 2003) have built a simulation model to improve the handling process of trucks at container terminals in ports. The overall project involved researching several different scenarios for the structure and management of Maasvlakte 2 in the port of Rotterdam.

A multi-agent system was introduced, not only to prevent the global sharing of sensitive information, but also to integrate different already in place (legacy) systems. The communication protocol used worked as an interface in order to allow for different simulation models to work together. The different simulations involved were the following:

- The truck generator model: This model was responsible for generating requests to the terminal for delivering and picking up containers.
- The road traffic model: Simulates the journey of trucks, and informs the terminal of unexpected delays.
- The container terminal model: this model simulates the steps performed at the terminal.
- Agent Based Planning and Scheduling Model: This model simulates the terminal and truck-agents negotiation for time slots.

Negotiation between truck-agent and terminal agent goes as follows: The truck agent will request the availability of a certain time slot. If this time slot is available, the terminal will grant the truck this time slot. If the slot is not available, the terminal will suggest another slot, keeping the truck-agent's requirements in mind.

The model discussed in Connekt (2003) involve several scenarios regarding the design of Maasvlakte 2. One of the most important questions relates to the required capacity of the terminal (where less required capacity is better). Every scenario combined several different concepts (one of which was time slotting).

The different scenarios were evaluated by experts on several criteria. The results (obtained from Connekt) are mixed. On the one hand, the scenarios in which time slotting is included are considered less usable because the risks of sharing information are regarded as too high. Furthermore the robustness and flexibility of these scenarios is considered to be rather low.

However, although the scenarios including time slotting were rejected by the experts, the results in simulation regarding time slotting are promising. By using time slotting to spread the peaks in traffic, the simulations show that terminal capacity can be reduced by 45% regarding the number of gate lanes, and 35% regarding the number of stack modules.

Relevance

This paper shows again the use of multi-agent systems as a means to combine several different legacy systems. Furthermore, the use of time slotting in truck transport is pointed out. However, the overall scenarios using time slotting are regarded as being too risky.

2.2.6 Road container transport II

Moonen (2009) implemented a multi-agent system for truck transport for the company Post-Kogeko. This company receives orders from customers to pick up containers from a terminal and deliver the container goods to a specified location. A trip is finished by returning the empty container to the terminal (essentially the same kind of trips as discussed in section 1.2). Scheduling is hard because customers usually place orders at most a day before required delivery. Furthermore, container release times from terminals are dependent on the (sometimes unknown) schedule of the terminal. For example, the exact moment when a container is placed on the stack or is released by customs.

The multi-agent system Moonen implemented contained several types of agents: the most important being the truck agent and the order agent. Truck agents look for orders and select an order based upon several criteria. One of the most important criteria was ‘empty mileage’, the number of miles the truck had to drive without cargo. Order agents keep track of all information regarding a specific order.

In field tests the MAS supported the human planners. The results were promising, although it became clear that a lot of work still had to be done. Besides a number of bugs, several situations were not taken into account by the system (for example, the MAS used a route planner for the Benelux only and different container types were not taken into account). The system provided the planners with planning suggestions the human planner had not thought of themselves.

According to the author, the inter-organizational environment plays a large role in preventing the adaption of a new system because it gives rise to the problematic factors “cost”, “standards” and “the legacy of legacy systems”: Involved parties already use several different systems, which makes it more difficult to adapt a new system to those old systems. Another issue is the hesitation of companies to share possibly competitive information and, with a large scale implementation, who is going to pay for what?

Relevance

Moonen performed both theoretical and real world tests. The results obtained were mixed: simulation results were disappointing compared to a similar simulation study that was used as a benchmark (in particular Mahr et al., 2008).

Practical tests showed that human planners were quite interested in new technologies to improve their scheduling. Regarding the results of this study, this is the most relevant point of Moonen.

2.3 Adoption of multi-agent systems in industry

Applications for e.g. malware (Roth, 2004), modern computer games and telecommunications (Luck et al., 2004) have been implemented as multi-agent systems. However, practical application clearly lags behind the academic enthusiasm for agent systems (Nwana & Ndumu, 1999; Paprzycky & Abraham, 2003; Moonen, 2009).

For example, the work of Douma (2008) (as discussed in section 2.2.4) was not developed any further than simulation (although a government pilot study is in progress) and Moonen (2009) (as discussed in section 2.2.6) only had test runs beside simulation runs.

Previous initiatives on multi-agent planning and scheduling show promise on the technological side (section 2.2): a lot of solutions are technically possible. The logistical problems in the port therefore appear not to be a technological problem as much as a business value problem. Earlier research has made the case that a multi-agent solution is technically possible and would have benefits to business, however, getting this business value out of these technological solutions proves to be more difficult.

2.4 Time slotting and other possibilities for improvement

Apart from software solutions such as multi-agent systems, several other suggestions for improvement are made in literature to solve the congestion issues. We will investigate some of these attempts, in order to be able to relate multi-agent systems to other possible solutions. Since these are mostly rather drastic infrastructural solutions, we expect the agent-based solution to be at least a useful addition to these other suggestions or perhaps even a better alternative.

2.4.1 Truck time slotting in the Los Angeles/Long Beach Ports

Lam et al. (2007) performed a study in which the truck movements in a LA Terminal in the Los Angeles/Long Beach Ports were measured. To this terminal, an appointment system was introduced by the authorities in order to decrease greenhouse emissions. There was a penalty (of $250) introduced to the marine terminals for every truck that was waiting longer than 30 minutes to enter the terminal gate.

One of the more interesting measures from this study is that the amount of trucks arriving at the terminal per hour were relatively well distributed. The authors suggest this may be caused by the appointment system. However, according to another study (Giuliano & O'Brien, 2007), the appointment system did not yield enough results because participation in the appointment system was too limited. Simulation shows that without enough participation in the system, the saved travel time is small.

Another interesting observation was that the waiting time in front of the terminal was low. On the other hand, the process time *on* the terminal was observed to be longer than the reported process times by the terminals. This may be caused by the fining system: a terminal does not have to pay a fine when the truck already passed the terminal gate. The waiting line just moved from in front of, to on the terminal. Unfortunately, this hypothesis is difficult to test because only after the appointment system was introduced data was gathered.

According to Giuliano & O'Brien, the appointment and fine system failed because it was imposed by an external party (the government) and caused resistance from the sector. Furthermore, the terminals were allowed to choose between an appointment system or extended operating hours. The terminals chose for the appointment system simply because it is less costly. Giuliano & O'Brien concludes that terminals are not interested in truck congestion.

Relevance

These studies show that an externally imposed (appointment) system does not yield the desired results. It also shows that the terminal should not be responsible for truck congestion because the terminal does not really have an incentive to solve the problem. However, as the results from Lam et al. show, arrival times at the terminal are distributed over the day reasonably well. This suggests some form of time slotting does spread out the trucks over the day. Perhaps the specific method of time slotting is not the right method, but it seems to us that some form of time slotting at least may yield positive effects.

2.4.2 The dry port concept

A more drastic way to decrease traffic and congestions at the sea terminal is to build hinterland terminals (Slack, 1999; Roso & Johan Woxenius, 2008). According to van den Broek et al. (2010), the hinterland is the deciding factor for transporters with regard to supply chain decisions.

The general idea behind a dry port is that cargo is transported from the sea terminal to the dry port in the hinterland by train (or by barge). From the inland terminal, the goods are consequently transported by truck to their respective customer. The advantage of this method of transport is that road traffic around the sea terminal decreases. The disadvantages include a possibly slower delivery and of course the costs involved in building and implementing the concept. An important requirement for an inland terminal is that the cargo flows are large enough to warrant the construction.

ECT already works successfully with inland terminals (Europe Container Terminals, 2011). Of course, successful implementation of the dry port concept is situation dependent. It is however, one of the methods of decreasing traffic on and around the sea terminal, and it is a method of moving transport flows from the road to train or barge.

Relevance

The construction of inland terminals shows that the congestion problem is taken seriously. The terminals are willing to take control of a bigger part of the supply chain: terminal haulage (Europe Container Terminals, 2011) is introduced. The dry port concept shows the willingness of the (sea) terminals to invest in better road transportation possibilities.

This seems in conflict with earlier observations. This apparent contradiction is solved by the reasons behind the terminal interest: the terminal gains more control of inland transport, which may turn into profit for the terminal. However, this may possibly be at the cost of the transport companies.

2.4.3 A chassis exchange terminal

As a method to implement "shaving" of traffic peaks, Dekker et al. (2012) suggest a chassis exchange terminal (CET). The general idea is to add a CET to normal terminals. On this CET, chassis with container are made available to the trucks. After the delivery of its container (or after arriving without chassis), the truck leaves its chassis at the terminal and picks up its next container from the CET. The CET is fed from the main terminal during the night when truck traffic to the terminal is low.

The implementation of a CET would substantially increase truck throughput on the terminal because there would be practically no waiting lines for picking up a chassis. According to simulations, the average waiting time for trucks was reduced by 83.2%. Implementation is rather costly: extra terrain needs to be prepared and terminal opening hours may need to be increased. However, according to the paper, implementation of CET is much cheaper than inland terminals.

Relevance

CET is at least theoretically a useful method for decreasing waiting times, peak shaving and increasing the speed of truck flow on the terminal. The implementation of CET may yield a large benefit. However, since the concept is largely theoretical, the exact benefits are unclear. On top of that, implementation seems rather expensive. This solution, more focused on hardware, may be a complementary measure together with better coordination like truck time slotting.

2.4.4 Conclusion

The three suggested improvements (forcing time slotting with fines, the dry port concept and the chassis exchange terminal) discuss several infrastructural terminal-focused solutions for solving the congestion problems in the port. These suggestions show that a central authority is not always capable of improving the situation (Giuliano & O'Brien, 2007), or that it is at least very costly to implement these solutions (Roso & Johan Woxenius, 2008; Dekker et al., 2012). On top of that, centralized solutions often require a big overhaul of the complete system, which would directly be opposed to our goals.

Although we did not investigate possible centralized solutions in detail, we feel that given the applicability of multi-agent systems to the transport sector (see section 2.1.2), the failure of a centralized appointment system (Giuliano & O'Brien, 2007), and that multi-agent system time slotting does not conflict with other (possible) improvements, investigation of a multi-agent system in more detail is desirable.

2.5 Discussion

As discussed in section 2.4.4, the problem in the port of Rotterdam conforms to the requirements for the application of multi-agent systems. However, as previous initiatives show (section 2.2 and 2.3), practical implementation lags behind scientific enthusiasm. The question remains why this is the case, and how the difficulties of implementation can be overcome.

One of the reasons for this issue may be that, generally, the solutions discussed in section 2.2 are focused on ideal circumstances: the current situation of the sector does not get as much attention as showing the (at least theoretically) 'optimal solution'. This may also be the reason why implementation beyond simulation has not been attempted in most cases (also see table 3).

Research:	**Sim:**	**Prac:**	**Noteworthy results:**	**Paper:**
Patient scheduling in hospitals	yes	no	Encapsulate legacy systems. Active scheduling and rescheduling.	Paulussen et al. (2003)
Multi-agent manufacturing control	no?	no	Implicit coordination	Valckenaers et al. (2002)
Airport planning	yes	partly	Multi-step planning Exploitation happens when possible.	Etschmaier & Mathaisel (1985); Beynon et al. (2002); Diepen et al. (2007)
Time slotting with barges	yes	in the near future	Waiting profile The use of sharing information demonstrated	Douma (2008)
Road container transport I	yes	no	Encapsulate legacy systems. Time slotting is useful. The overall concepts are useless Time slotting shows promise	Boer et al. (2003)
Road container transport II	yes	partly	Shows the added value of MAS for human planners Practical tests show promise.	Moonen (2009)

Table 3: The different papers of the literature research.

Multi-agent systems are applicable to our problem, literature shows promising results with regard to multi-agent systems, but practical implementation lags behind. Because practical considerations and implementation are considered to be very important, we should take extra care to ensure that our system will be implementable.

We would argue that the approach taken in this research is somewhat different than in (most) of the studies discussed. In our research optimization (minimization of travel time) is important, but it is not as important as practical considerations. Because of these practical considerations, an essential part of the research performed is a field study. In chapter 3, we explore the port in its current state and the parties involved. By doing so we hope to capture the essence of the actual problems in the port, and the actual considerations of the different parties. Based on the literature and field study combined, we will come to several design decisions with regard to implementation in chapter 4.

In this project, the implemented simulation is not so much meant to demonstrate the technological optimality, but to demonstrate a feasible and implementable multi-agent system. Having reviewed the literature, we feel that the case for multi-agent systems has been proven to work in theory. Now it is time to look at the practice.

Chapter 3

Container transport by truck

The previous chapter reports on the literature with regard to multi-agent systems in general and (possibly) useful multi-agent planning systems. The aim was to examine the usefulness of MAS for the truck time-slotting problem in the port of Rotterdam.

As explained in chapter 1, it is the goal of the research reported in this thesis to be a first step toward practical implementation. In order to make this step, investigating the environment of the implementation is essential.

In this chapter several different parties involved in container transport by truck around the port of Rotterdam will be investigated in more detail. The aim of this chapter is twofold: find out the workings of the current process and find out which parties are actually interested in the implementation process. These aims result in the following research questions:

RQ3. *What are the current problems in truck transport?*

RQ4. *Which party can facilitate further steps in the implementation process?*

In section 3.1, the processes on the Euromax Terminal will be discussed. Section 3.2 will discuss several transport companies, the bottlenecks they experience and the willingness to adapt to a new situation. Several "umbrella" organizations will be discussed in section 3.3. In section 3.4, the research questions will be answered.

3.1 Euromax terminal

The terminal companies are responsible for the transfer of goods between sea ships, barges, trains and trucks. Terminals have their own systems to regulate the flow on the terminal. This section is based on an interview with Johan Hoekwater, Manager Logistics Development. The notes of this interview can be found in appendix A.1.

Obviously, the Euromax terminal is not the only terminal in the port. But because the Euromax terminal has one of the fastest turnaround times in the port (see appendix A.1) and because both Euromax and most other terminals in the port of Rotterdam are owned by ECT, we feel that this field study is at least indicative for the working of terminals in general. ECT is one of the larger container terminal operators in Europe (Europe Container Terminals, 2011).

Figure 7: The Euromax Terminal (picture taken by Hans Moonen, on the 18th of August, 2011).

The Euromax terminal makes use of almost fully automated cranes and fully automated lorries (AGV's, automatic guided vehicles). On arrival, a truck gets specific instructions on how to proceed. By rigidly regulating the flow of goods on the terminal, Euromax has one of the fastest turnaround times in Rotterdam.

Still, there are several issues that disturb an efficient container flow. The first issue has been discussed before: sharing information. Sharing correct information can influence the processes at the terminal in a huge way. The terminal has no idea on truck arrival times before the truck physically arrives. Of the information the terminal does receive, about 60% is incorrect (Appendix A.1, also confirmed in the literature, see Connekt, 2003). Correct information can help the terminal preparing for truck arrival: for example the terminal could decide to put a container in a different stack, which could optimize transport.

The second issue is the truck arrival moment. There are two rush hour moments, one in the morning around 7 am, and one in the evening between 5 and 9 pm (Connekt, 2003). On top of that it is also rush hour for normal traffic during those hours (van der Horst & de Langen, 2008).

Driving at night is not a viable solution (Connekt, 2003). Working at night is too expensive for the transport companies, and (local) authorities oppose loading/unloading at night because of the noise.

Regarding the delays at the terminal, two different types of interrelated, but separately distinguishable delays can be identified: there can be a delay for the terminal as a whole, but there can also be delays specifically for one stack.

The containers at the terminal are stored (on average 7 days) in different stacks. A stack can only service one truck at a time. So if, for example, at a certain moment in time 3 trucks arrive at the terminal and the containers the trucks are planning to pick up are all located in the same stack, only one truck can be serviced at a time and the other two will have to wait. However, when the three trucks have to pick up a container at different stacks, they can all be serviced at the same time.

The third issue is trade union rules. Because there are different types of trucks, placing a container on a truck cannot (yet) be done automatically. The truck driver would be perfectly capable of performing this task. The union however, protecting the rights of port workers, prevents the truck drivers from performing this task. The terminal has to hire personnel specifically for walking between the stacks to perform this task. When a truck arrives at a stack without a terminal worker present, it will have to wait.

Another issue related to union rules is the workers shift. At a quarter past three, everyone at the terminal stops working. All the personnel gets in a bus and drives to the parking lot. At the parking lot, everyone gets out of the bus, and the new shift gets in to get driven back to the terminal. When the new shift arrive at their stations, they have to figure out where the container currently picked up has to go (on the stack or off the stack), before work can be resumed as normal. This causes a delay of 15 to 20 minutes and initiates the evening rush hour.

The Euromax terminal is working on its own solutions to increase their efficiency (Europe Container Terminals, 2011), and the terminal is not particularly interested in working on a solution with other directly involved parties. This is in line with the literature, which says that terminal companies are not that interested (yet) in the problems of delays in the hinterland (Connekt, 2003; Douma, 2008; Kolkman, 2009). This is mainly because the terminal does not have a direct benefit and no obligation to solve these problems. There is no contractual relationship between terminals and transport companies. However, the Euromax terminal does have an interest in the results of this research. Their solution may be compatible with ours.

The fact that Euromax is looking for solutions themselves may indicate a (slight) change in attitude: apparently the terminals start to care about the hinterland. This may be brought about by the construction of terminals of the competing firm APM on the new Maasvlakt 2.

3.2 Transport companies

The transport companies are responsible for transporting the containers from and to the terminal. Usually they are contacted by the customer to pick up and deliver a specific container. Most transport companies are represented by TLN (±6000 in total). Transport companies vary greatly in size: Post-Kogeko for example operates ±500 trucks, while there are also truck companies with only one or two trucks.

3.2.1 The VZV

We attended a meeting of the VZV (Vereniging van Zeecontainer Vervoerders; *English*: the Association of Sea container Transporters), an association of several transport companies in the business of transporting containers. The VZV has ±50 transport companies as their members (Zeecontainervervoerders, 2011). The organization is a subsidiary of TLN. The theme of the meeting was dynamic planning. Two short talks started up the discussion among the attendees. The meeting report can be found in appendix A.3.

One of the points made in the start-up talks was that airport planning is not very different from truck planning. The thesis was that container transport could be, just like airport scheduling is, forcefully optimized by instituting time slots. In airport planning huge fines make sure everyone tries their best at keeping their appointments.

However, as discussed in chapter 2.2.3 there is a significant difference between airport planning and truck container transport. There is a third party with influence: the customer. The customer decides at which time the container should arrive, not the transport company. This also makes traveling during nights and weekends unlikely: the customer wants its container to arrive during the day. Negotiation between terminal and customer is not expected to happen. However, negotiation between the transport company and customer may be possible.

Another suggestion made was to raise the price of container transport for customers in peak hours, attempting to motivate them to choose different arrival moments. If every transport company would change to this method of charging customers, this could work. However, because of the stiff competition between transport companies, the customer will always be able to find a company who will transport the goods for the same old lower price, making this "solution" unrealistic. The current business model: payment per kilometer, is therefore difficult to change.

The main problem is the conservativeness of the transport companies. The tactics employed by transport companies involve static planning and reactive adaption to sudden issues, instead of pro-active dynamic planning. Suggesting for example that a truck could “start doing something else” (drive to a different terminal, for example) because of more recent and relevant information, was a bridge too far for the transporters.

The conclusion that can be drawn from this meeting is that transport companies should be convinced of the utility of dynamic pro-active planning. This includes stopping to view the time the customer sets for getting its container as a static parameter. The hope is that the simulation discussed in this paper will help convince the transport companies of the benefits of dynamic planning and may even convince the costumer to take (more) responsibility for the time of arrival they choose.

3.2.2 Meeting individual companies

On the 21st of December, 2011, we had three meetings with three different transport companies: Hebra (50 trucks in container transport), van der Most (80 trucks in container transport) and Post-Kogeko (51 trucks in container transport). A detailed summary of the different meetings can be found in appendix A.4.

Although all three companies are involved in container transport, the companies seem to vary in size, objective and openness to innovation. For example, Hebra and van der Most focus mostly on the longer trips, while an important part of the transport for Post-Kogeko is inter-terminal transport. The companies also have a varying amount of reefer (a refrigerated container) usage: for van der Most it is around 10%, while Hebra has up to 50% reefer transport.

Hebra and van der Most take part in Truckload Match: an inter-company collaboration to decrease empty miles. Van der Most is unique in the sense that they have their own depot and cranes, where they can turn over and store containers.

Post-Kogeko is taking part in Cool Barge. This is a collaborative with barges, several customers and transport companies to facilitate intermodal transport. Reefers are transported by barge between the Waalhaven and the Maasvlakte, in order to avoid congestion on the A15.

Although all three companies are involved in these kinds of innovative projects, during the interviews it appeared to us that there is a difference in attitude toward innovation. At Hebra, for example, the planning for the trucks is fully done by hand, even though at the moment fully automatic transport management systems are available. On the other side of the spectrum, at Post-Kogeko, Ben van Zeijl told us that he is not directly looking for a return on investment in innovative projects (like Cool barge). It is more important to him that new things are tried out, in order to push the sector forward. These examples demonstrate the conservativeness of Hebra, and the willingness to adapt and innovate at Post-Kogeko.

This may be caused by the low margins per container the companies obtain: There is not a lot of "wiggle room" for these companies to attempt new things. In absolutes, larger companies will have more room for "experimentation", than smaller ones (container transport is only a small part of Post-Kogeko's business, while it is Hebra's only business).

Although there are several differences between these three companies, the problems indicated by these companies are generally the same. The main problems according to the transport companies are:

- The lack of transparency and communication by the terminal.
- The (seemingly) endless debate regarding whose responsibility the waiting time in front of the terminal is.
- A general lack of information sharing between transport companies, which results in difficulties when responding to unexpected events.
- Because of the heavy competition between transport companies, the transport companies together cannot take a stand against the customers or terminals.

The overall conclusion is that information sharing can improve decision making. However, according to the people we talked to, this information will only be useful in (very) specific circumstances. This is because transport companies have little "wiggle room": customer demand is strict, profits per transport are low and terminals are static and only concerned with the business on the terminal. There are many constraints to planning, and therefore there is little room for flexibility.

The division of power in the sector causes the transport companies to be in the worst spot of a prisoners dilemma: significant improvements for the transport companies (and consequently everyone) can only be achieved by significant investments of the terminal and customers. On the other hand, as the Truckload Match system shows, even when the yield is very low, a small yield can still be useful to transport companies. And no transport company thinks large benefits are achievable by better planning anyway (at least not without significant costs). Because large changes are difficult to obtain, it is important to note that even small changes are considered useful.

Optimization seems to be beneficial for all parties in only one part of transport: the transport time *on* the terminal. This is the only part in the transport cycle where the terminal actually has a direct benefit from optimization. Optimizing the placements of containers in stacks and optimizing the spreading of trucks over the different stacks should be beneficial for the customer and transport company as well. Perhaps the focus should lay here.

3.3 "Umbrella" organizations

In this section several involved parties operating as umbrella organizations, or at least parties that (should) have an interest in overall port efficiency, will be discussed. These parties are not directly involved in container transport.

3.3.1 Port authority

The port authority, owned by the city of Rotterdam and the Dutch government, exploits and develops the port area within Rotterdam (*Port of Rotterdam Authority*, 2011). The goals of the port authority are twofold:

- Sustainable development, exploitation and regulation of the port of Rotterdam.
- Smooth and safe handling of shipping.

The port authority operates as an independent company since 2004. Its mission is to develop the port of Rotterdam into a port of world class. As such, it is a company that has the overall efficiency of the port in mind. The focus, however, as stated in the company goals, is on shipping, not container transport.

The authority was heavily involved in the development of Maasvlakte 1, and is involved in the development of Maasvlakte 2. Also, the port authority is initiator of Portbase (Portbase, 2011), a platform that strives to be the ultimate platform for logistics in the Netherlands.

3.3.2 Verkeersonderneming

The "verkeersonderneming" (English: "Traffic Enterprise") is an organization involved in decreasing and regulating traffic on the main road from and to the port of Rotterdam: the A15. The verkeersonderneming was founded by the city and city region of Rotterdam, the port authority and the Dutch government. (Verkeersonderneming, 2010a)

To accomplish their goals, the verkeersonderneming invests in traffic management: optimizing the use of the A15 and mobility management: convincing road users not to drive during rush hours.

3.3.3 Transport and Logistics Netherlands

TLN is the biggest and most important advocate for the road transport and service sector. TLN has more than 6000 members (TLN, 2011).

TLN represents the road transport sector as a whole. It attempts to speak for the whole sector. It lobbies at governments and it concerns itself with for example troubles with eastern-European drivers, criminal behavior in the transport sector and transport efficiency (Transport en Logistiek Nederland, 2011).

3.4 Conclusion

In subsection 3.4.1 the current bottlenecks in container transport will be summarized. In subsection 3.4.2 we return to the question whether multi-agent systems are applicable to the situation in the port of Rotterdam. Subsection 3.4.3 will discuss the considered solutions from the sector. In subsection 3.4.4 we will investigate which parties want to take steps toward implementation.

3.4.1 Current bottlenecks in container transport

According to the transport companies, the logistics market is stuck at the worst state of a complicated prisoners dilemma. The focus of the terminals is to keep the turnover time *on* the terminal as low as possible. Waiting time *in front of* the terminal, even if caused by the terminal, is blamed on (and paid by) the transport companies. The terminal cannot be forced to make changes by the transport companies because a contractual relationship between the two is lacking. On top of that, there is no incentive for the customer to change the terminal or, at least, communicate with the terminal.

The terminal, on the other hand, would point to the fact that things are changing. Although the focus of the terminal remains on the sea-side, the land-side is getting more attention. This change of focus is brought about by the changes within the port. ECT used to have a monopoly position in the port of Rotterdam. With the coming of Maasvlakte 2, run by the new terminal company APM, competition between terminals may improve the situation on the road side.

The current business model of the transport companies is payment per kilometer. There is a fierce competition between the transport companies, which makes it impossible to change this to, for example, payment per hour: making the customers care by increasing prices when extra costs are made is a good way to send your customer to a competitor for the next order. Because of the old business model, the margins for transport companies are low, and their budget for innovation very small.

A seemingly obvious solution: driving at night and in weekends is unfeasible because this will be expensive for the transport companies, would produce noise to which local authorities are opposed and goes against customer requirements.

The problem at the core is that the transport sector is too scattered to take a stand. The terminals and the customers hold positions of power, and the transport companies are caught in between. It is difficult to find a solution in a situation where the parties with power will not take responsibility for the problems.

A related issue is the lack of information sharing between parties. The field study reveals that the terminal complains because they do not know when the trucks are arriving, and the transport companies complain because they are not informed when there are unexpected delays at the terminal. In the next chapter, the goal is to show that sharing information regarding arrival times, technical difficulties, delays and other issues would improve the situation for everyone.

3.4.2 Applicability of multi-agent systems to the port of Rotterdam

From the previous subsection we can conclude that there is a conflict of interests between the different parties involved in the port. Furthermore, information sharing is lacking. Both of these aspects make a centralized solution infeasible.

The situation in the port of Rotterdam is distributed, and because of the many factors influencing planning, there is a high degree of dynamics in this process. Cooperative process do exist in the port, and the different parties are willing to work together.

In section 2.1.2 we described reasons for using a multi-agent system and reasons for not using a centralized solution. Based on the field research, we conclude the transport sector in the port of Rotterdam applies to the criteria as stated by Fischer et al. (1996) and Marik & McFarlane (2005). Therefore, we conclude that a multi-agent system is applicable to the port of Rotterdam.

In our simulation, we will investigate the application of a multi-agent system to this kind of situation in more detail. In our conclusion (chapter 6), we will reevaluate the answer to this research question.

3.4.3 Proposed solutions

In subsection 3.4.1 we summarized the problems as they currently exist in the port of Rotterdam. The port reports we investigated also list several issues and possible solutions (see appendix A.5). Several solutions were proposed:

- Decoupling of container and truck at terminal pick-up.
- Involvement of customer (by negotiating prices and/or truck arrival times).
- Better communication between the different parties (customer, terminal, transport companies) with regard to truck arrival times and delays at the terminal.

Of course, not all of these solutions are valued the same by all parties involved. Decoupling truck and container was proposed by the terminal, but transport companies may not see the direct benefit. Involvement of the customer may be a solution but the transport companies do not think this to be a workable one. In table 4 the solutions (in their broadest sense) and the opinion from the stakeholders, as perceived, are displayed.

	Terminal	Transport company
Decoupling container truck	Positive	Reserved
Involvement customer	No opinion	Negative
Better communication	Positive	Positive

Table 4: The stance of the terminal and transport company on proposed solution.

Because the transport companies as well as the terminal value better communication, this should be the main focus for improving the situation. Implementation of other solutions will require convincing the transport companies.

3.4.4 The parties involved in taking further steps

In order to avoid confusion: in this section the party to facilitate implementation, not regulation of the multi-agent system. With regard to design and implementation, a central party should facilitate this process. Getting all relevant parties around the table and by ensuring all these parties are represented fairly in the agent system would be the task of this party. However, in execution, this facilitating party should not be the central decision making unit because, as we explained in section 2.1.2, a multi-agent solution fits better with the problem.

Because the terminals hold a position of power, the terminal is a likely first party for taking initiative. Especially because everyone (terminals, transport companies and customers) benefits from a smooth transition on the terminal. However, as can be read in section 2.4 and 3.2.2, the terminal may not have the best interests of the transport companies in mind. This makes the terminal a desirable participant, but a less suitable facilitator.

An alternative would be for the transport companies to take a collective stand against the terminal and their customers together. For example, by collectively reforming pricing they would be able to make the customer (and consequently the terminal) care more about the delays caused by the terminal. However, such a collective stance is unlikely and perhaps even illegal: making price agreements may not be permissible.

In any case, even voicing a collective opinion toward the terminal (like the VZV and TLN are doing somewhat successfully), would stimulate positive changes in the sector, and facilitate changes to (for example) a multi-agent system solution. However, even if the transport companies would be able to make a collective stand, just like the terminals: self-interest of the transport companies would make them an unsuitable facilitator of the implementation process of a multi-agent system.

The VZV and/or TLN, although these may be able to play a role in representing the transport companies, are not influential enough and too biased to take the responsibility for improving the situation themselves. The verkeersonderneming may be good in a supporting role, since their goal is to decrease traffic on the A15. However, the overall responsibility of facilitating the process should lie with the Port Authority. The Port Authority is the only party with the overall efficiency of the port as its main objective and, on top of that, it has the power to encourage change. The creation of Portbase (Portbase, 2011) also shows that the port authority is capable and willing to provide centralized and neutral methods of the sharing of information.

Chapter 4

Agents in container transport

As is argued in chapter 2, (multi-)agent systems can be applied to many situations. It was also determined that MAS is an applicable software paradigm to apply to the transport sector. However, before applying this paradigm to this specific situation, restriction of the paradigm to the situation and/or adaption of the situation to the paradigm is required.

As explained in section 3, fundamentally changing the current situation would prove to be very difficult. Therefore, the choice was made to implement our multi-agent system in such a way that it would improve the current situation without fundamentally changing it. The proposed improvements, as discussed in subsection 3.4.3, will be investigated in relation to the earlier solutions reported in the literature (section 2). The research question to be answered in this section therefore is:

RQ5. *What kind of agent system in what form would fit container transport in its current form?*

What we mean by "its current form" is that we do not want to change the operations performed significantly. We want to avoid changing the current power balance.

In section 4.1, the method of negotiation between agents will be discussed. Section 4.2 will investigate the potential for a more dynamic way of container transport and section 4.3 will explain the choices with regard to time slotting. Although the focus is mainly on the waiting time and delays on and around the terminal, time on the road and traffic jams are also considered in section 4.4. In the discussion (section 4.5) we will answer the research question.

4.1 Negotiation

Coordinating time slots and to allow every party to take part in the decision process requires some form of negotiation. As explained in section 2.1.1, a multi-agent system can use implicit or explicit negotiation. Explicit negotiation means that the agents are in direct negotiation with each other to achieve their (common or selfish) goals. Introducing a (custom) monetary system to facilitate these negotiations is a method to facilitate explicit negotiations (for example, see section 2.2.1 and section 2.2.3).

Implicit negotiation, on the other hand, means that agents operate by 'local rules': an agent directly acts on input from others in a way it sees fit (for example, see section 2.2.2).

The advantage of explicit negotiation as opposed to implicit negotiation is that individual agents are explicitly in control regarding their own actions and can therefore take their own (individual) precautions to prevent exploitation. The disadvantage is the time and resources required to perform explicit negotiation.

There is no explicit negotiation between truck and terminal on truck arrival time in the current situation. Introducing explicit negotiation, a custom monetary system and/or implementing measures to prevent cheating would significantly change the current situation. This would require a big investment and willingness from the terminals and the transport companies because every party has to change their way of working significantly.

Implicit negotiation relies on local rules of agents to make decisions. Although exploitation is also possible with explicit negotiation, exploitation with implicit negotiation is more probable because by using implicit negotiation, there is no control mechanism within individual agents to ensure every agent is playing by the rules. This makes implicit negotiation suitable only in specific circumstances:

- The system is controlled by an objective, independent and external authority; and/or
- Agents are trusted to keep the common interests in mind; and/or
- Agents operating in their own interests do not interfere with the common interest.

Introducing a central authority to facilitate negotiation is counterproductive: one of the goals of introducing a multi-agent system is specifically to avoid a central control system. Trusting the agents to make decisions with consideration of the common good is also not an option. The transport companies are direct competitors which makes trust an issue.

The solution, therefore, is designing the system in a way, such that agents operating in their own interest automatically operate in the interest of everyone.

In that way, exploitation can be avoided.

Every party involved wants to perform their operations as efficiently as possible. However, what may be an efficient action for one party may be working against the interests of other parties. Different parties have different interests. This limits possible solutions to the basics: common interests for everyone.

As explained in chapter 3, the terminal focuses more and more on the efficiency of the road-side of transport. Their direct interest regarding the road-side, as explained in section 3.1, is the transport time on the terminal.

As pointed out in section 3.2, a more efficient flow on the terminal would also benefit the transport company, as it is a a part of the transport cycle for the truck as well.

Every party involved has an interest in optimizing the flow on the terminal. The goal is to exploit this common goal in order to encourage parties to perform actions not directly benefiting their own agenda. This will be further explained in section 4.2.

4.2 Decoupling container and truck

At the terminal (The Euromax terminal for example, also see appendix A.1), containers are placed in several different stacks with different cranes. Per stack only one truck can be serviced at a time. In the current situation, a planner assigns a truck driver to pick up or deliver a specific container at the terminal (usually without knowledge on stack placement). If several trucks need containers from the same stack, a waiting line forms at that stack.

By "decoupling" the trucks and the containers, trucks will be able to pick up a different container (for the same company of course) from a stack with a shorter waiting line. If trucks communicate their expected arrival time up front to the terminal, the terminal can inform the truck on the relevant stack waiting times.

Transport company planners can, based on this information, decide which container to pick up. This decision will depend on customer requirements, total waiting time reduction and other considerations. The terminal could promote the behavior of container switching by spreading out the containers of one company over the different stacks. In fact, the terminal even suggested this (possible) improvement (see subsection 3.4.3).

The direct benefit of sharing arrival time information for both the truck company and terminal would be a reduced stack waiting time. The indirect benefit is that, when this functionality is implemented, information regarding expected arrival times is acquired. This information can consequently be used to improve not only the stack waiting times but the terminal waiting times as well. As concluded in section 3.4.3, sharing relevant information is something the terminal as well as the transport companies see a benefit in. The method of using truck arrival times to improve the terminal waiting time will be discussed further in the next section.

4.3 Time slotting

Time slotting involves scheduling or allowing trucks to schedule themselves in such a way that, in the optimal situation, no more than the maximal amount of trucks that can be serviced at a specific moment in time are at the point of service at that time. The time-slotting of trucks can be accomplished explicitly or implicitly.

In explicit time slotting, when a truck has a container to pick up or deliver at the terminal, the truck-agent will contact the terminal to reserve a suitable time slot. If the truck arrives too early at the gate, it will have to wait. If the truck arrives too late, the reservation will expire, and the truck will have to make a new reservation.

As pointed out in section 3.2.1, time-slot negotiation is not applicable to truck transport because a third party (the customer) needs to be involved as well. Because explicit negotiation with regard to time slots is absent in the practical setting right now, implementation of this would prove to be more difficult. As explained in chapter 1, we are not looking for a great overhaul of the system. And in this case, neither are the transport companies. There is some research that suggests that moving in this direction does not yield the required benefits (see section 2.4.1). Implicit time slotting therefore seems the more sensible solution.

When implicit time slotting is used, the truck will simply communicate its expected arrival time to the terminal instead of negotiating this moment. The planners of the transport company will be able to plan the departure time of the truck besides other considerations based on the *waiting profile*.

The terminal waiting profile (or terminal profile in short) based on the waiting profiles by Douma (2008) (also see section 2.2.4) will give an estimation of the waiting time at the terminal for an entire day in the form of a graph. When the truck (or the planner) knows an estimated arrival time, this will be communicated to the terminal (as is discussed earlier, to gain access to the *stack waiting times*). The terminal will consequently update the terminal profile for other trucks and communicate its terminal profile to relevant parties. When the truck is delayed, an updated expected arrival time should be sent to the terminal.

Implementing terminal profiles will provide transport companies with real time information on the waiting time at a terminal. This extra information allows the planners to make better decisions because they will be able to plan departure times better. The truck companies will have the responsibility of time slotting and also the freedom to consider other factors besides terminal waiting time. By regulating the stack waiting lines, the information required for the terminal profiles is already available. The only thing the terminal has to do is share this information with the transport companies.

4.4 Road and other waiting times

Waiting profiles can also be applied to other parts of the transport cycle. Waiting time on the road (traffic jams) can be represented using waiting profiles as well. The waiting time at the customer and at the container depot where empty containers can be delivered, can also be integrated and represented by a waiting profile. The only thing required to set this up is the correct information.

4.5 Discussion

By giving the transport company a direct benefit, the idea is that the companies are stimulated enough to provide reliable arrival information. This arrival information can be used to benefit trucks directly, but it can also benefit the terminal and transport companies in other ways. In this section, we discussed several design choices:

- We will make use of implicit negotiation of time slots by means of waiting profiles.
- Terminals will be able to compile and distribute waiting profiles based on the information provided by the individual trucks.
- Truck container decoupling is made possible by provision of actual waiting time estimations of containers by the terminal. It is up to the transport company to use this information to perform a container switch.
- Road and other (customer or depot) waiting times are available in the system which can also be used by the transport companies for better decision making.

The approach to implementation for this kind of system would be on a voluntary basis. As explained, the transport companies and terminals should be stimulated by the direct, short term benefits they gain by participating. However, the participation does not have direct benefits in all circumstances. Informing the terminal about picking up a container at a specific time can have a direct benefit on the stack waiting time: the terminal can provide information with regard to which container is convenient to pick up. However, delivering a container at the terminal does not have such a benefit. In a system on a voluntary basis, transport companies may slack on informing the terminal in this situation. This may threaten the system as a whole.

Another risk is the amount of direct benefit of container selection for the transport company. There are several factors that can influence the feasibility of a container switch, like:

- Customer requirements;
- Truck limitations (not every truck can handle every container);
- Driver limitations (Drivers can only drive a limited amount of hours);
- A difference between the actual compared to the predicted time saved.

In order to move on to actual implementation, the first versions of the system should work on a voluntary basis. If it turns out that participation is insufficient and the system does not yield (enough) benefit because of that, some sort of enforcement or positive stimulation will be required.

With regard to the actual benefits of the container switch possibility and other benefits that are expected to be gained, it is difficult to establish whether these benefits are worth the investment until an actual implementation is attempted. In the following section a simulation of the system is discussed, and the benefits of the improvements as suggested in this section are tested.

Chapter 5

Real-time multi-agent time slotting

In this chapter the implementation of a real-time multi-agent truck time-slotting system will be discussed. In section 5.1, the agent design will be explained. Section 5.2 will discuss the different agents in the system, and section 5.3 will discuss the decision moments during the transport cycle.

Because the building process itself gives insight in the problems and complexity of building a system (Nunamaker et al., 1991), we will discuss this process in section 5.4.

Consequently, in section 5.5, we will discuss the input of the system and its output together with the parameters we have set.

After discussing the specifics of the simulation, the next sections will attempt to answer the following research question:

RQ6. *Do the suggested improvements actually decrease waiting time?*

The design of the simulation will be discussed in section 5.6. Section 5.7 will discuss the results and in the discussion (section 5.8), we will attempt to answer the research question. In conclusion we will evaluate the work done (section 5.9).

5.1 Agent design methodology

Because the aims of this agent system are compatible with the Gaia methodology for agent-oriented design (M. Wooldridge et al., 2000) and because this method offers a structured and systematic way for agent design, Gaia was used to help the agent design. M. Wooldridge et al. listed several characteristics of domains where Gaia would be applicable, the most important one being the following: The goal is assumed to be the maximization of some global quality measure. In our case the goal is to reduce travel time.

The Gaia methodology helped in clarifying the roles, responsibilities and interactions within the system and to find the most sensible way to divide responsibilities over the different agent types. In appendix B.1 the schedules of the various roles and responsibilities can be found.

The Gaia methodology designs agent types using a responsibility based design: discover the roles and responsibilities within a system and try to map these roles and responsibilities to agent types. As M. Wooldridge et al. (2000) would describe: *"An agent type is best thought of as a set of agent roles."* (p. 12).

As explained in chapter 3, it is important to relate the agent design to the current situation in the port. Therefore, an entity based approach to the agent design was attempted as well because the current existing entities are important factors in the process. On top of that, these entities are unlikely to change. The following (complementary) guidelines were used:

- In order to remain autonomous, every company should be represented by their own agent.

- "Agentify" the environment: every relevant entity should be represented by an agent (Valckenaers et al., 2002).

The specific agents are found by "copying" the agents as they exist in the current system to the simulation. In terminal truck time slotting, the relevant stakeholders are the terminals, the transport companies and the customers. These stakeholders are agentified.

The results of these design processes mostly converged to the same solution. Only one conflict arose with regard to the waiting-profile-role. The responsibilities of the waiting-profile-role would be to: Keep its waiting profile up to date and communicate its waiting profile. This role would be shared between the terminal and the stack. Thus, according to the Gaia methodology, no separate stack and terminal agent types should exist because agents should not share a role. The Gaia methodology would propose a waiting-profile agent type.

However, using the entity-based approach, the terminal and stacks are clearly identifiable separate entities, even though these share (some) roles and responsibilities. Given the fact that in practice the terminal has more responsibilities than the individual stacks, and the fact that the terminal has a coordinating role, we chose to favor the entity-based approach to the responsibility-based approach. Therefore we built a stack and a terminal agent type.

In the next section, we will discuss the result of this design process.

5.2 The agents

In section 3.4.4, we identified the relevant parties in the port. Using the Gaia methodology, we identified multiple roles in single companies. Therefore, "the stakeholder" agents are assisted by several "subordinate" agents. Table 5 gives an overview of the stakeholders and their agent representation.

Stakeholder:	Agents:
Terminal:	Terminal Agent Stack Agent
Customer	Customer Agent
Transport Company	Transport Company Agent Truck Agent

Table 5: The different stakeholders and their agents.

In addition to the agents that resulted from both methodologies, the Gaia methodology itself identified four important responsibilities that resulted in adding another three (supporting) agents to the system. Table 6 gives an overview of these agents.

Responsibility:	Agents:
Initializing of the agents Shutting down the agents	Initiator Agent
Managing the simulation iterations	Simulation Management Agent
Providing route information	Transport time estimation Agent

Table 6: The different responsibilities and their agents.

The responsibilities of all the agents are summarized in table 7. Given these responsibilities, the specific intra-agent communication is clarified as well. The communication lines between the (main) agents are displayed in figure 8.

5.3 Decision moments

During the transport cycle, there are several moments in which adaptation of the cycle is possible. In this section we will explain per cycle the decision moments and their implementation in the simulation. There exist two cycles which are distinguished in the following way: either a container is picked up at the terminal, or a container is delivered at the terminal (see figure 9).

In the situation where a container has to be picked up at the terminal, there are three decision moments. These decision moments are displayed in table 8,

Agent:	Responsibilities:
Terminal Agent	• Keep own waiting profile up to date. • Communicate waiting profile to transport companies. • Compile container stack information.
Stack Agent	• Keep own waiting profile up to date. • Communicate container information.
Customer Agent	• Place orders and provide order information.
Transport Company Agent	• Receive orders. • Assign orders to trucks.
Truck Agent	• Execute order (drive). • Keep terminal up-to-date on arrival time. • Arrange possible container switches.
Transport Time estimation agent	• Provide anyone who asks with transport time estimations.
Initiator Agent	• Start up the simulation agents. • Shut down the simulation agents.
Simulation Management Agent	• Manage individual simulation runs.

Table 7: The roles of each agent.

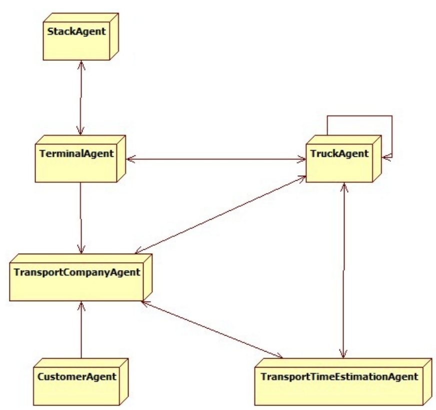

Figure 8: Agent communication diagram.

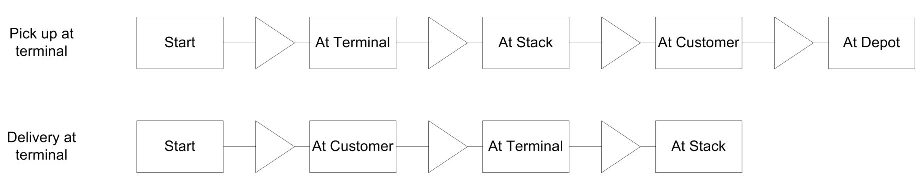

Figure 9: Both transport cycles.

together with who (which agent) is making the decision and what the decision is about.

Agent	at the start:	before terminal:	before depot:
Customer	trip information	-	-
Trans. comp.	which truck departure time		which depot
Terminal	which stack (container only)	-	-
Truck	-	which container	-

Table 8: Who is making decisions when and about what, for a pick up at the terminal.

In the event a container has to be delivered at the terminal, there are two possible decision moments. These decision moments are displayed in table 9, together with who is making the decision and about what a decision is made.

	at the start:	before terminal:
Customer:	trip information	-
Trans. comp.:	which truck departure time	-
Terminal:	-	which stack

Table 9: Who is making when decisions about what, for delivery at the terminal.

Decision moments are always located in between locations ("we have completed x, what are we going to do next?"). However, not every 'in between' moment is a decision moment. For example, when a truck has picked up a container at a terminal, it obviously cannot decide to deliver this container at another customer.

In the simulation, various methods of decision making are used. Some of these methods are manipulated in our experiments. For example, orders which are generated by the customer are generated randomly in all cases. Another example is the departure time of a truck: this departure time can be chosen such that the shortest possible travel time is achieved while the customer arrival requirements are still met. The other method would be to depart immediately. The specific manipulation on decision moments is discussed in section 5.6. The methods of decision making are displayed in table 10.

In the program, each responsibility (table 7) maps to a specific behavior. And within each behavior, decisions are made according to table 10. In appendix B.2, the behaviors of the agents (which map to their responsibilities) are described in more detail. In the next section our experience with the Java Agent DEvelopment framework (JADE) is discussed.

When:	What:	How:
At the start	trip information	random
	which trip for which truck	in order of required arrival time at customer
	which departure time	based on terminal waiting profile/immediate
	which stack	random
before terminal:	which container	based on stack waiting profiles/based on initial choice
before depot:	which depot	random

Table 10: How decisions are made.

5.4 Building the prototype

The fourth step in the design cycle is building the system (see section 1.4). Nunamaker et al. (1991) explains that important aspects of building the system is to *"provide researchers with insights into the advantages and disadvantages of the consepts, the frameworks, and the chosen design alternatives. The Accumulated experiences and knowledge will be helpful in redesigning the system."* (p. 100). In this section, we will discuss the process of building the prototype and describe the difficulties we encountered.

The design and implementation of the agent system ultimately took a lot more time and work than initially expected. We worked on the simulation for over half a year. Although being experienced with programming and Java, the unfamiliarity with the development framework JADE made the implementation of this agent system quite the learning experience.

First off, with regard to programming agents, it turned out to require a different perspective at programming than the more traditional object oriented programming. Inheritance and accessing objects had to make way for requesting and receiving information to and from other agents, functions became behaviors and programming errors usually turned out to be communication difficulties.

Almost every time we implemented a new behavior, we were confronted with the fact that before decisions could be made, communication with one or more other agents was required. This made behaviors quite different from simple functions because the behavior first has to consult and consequently wait for the answer from another agent(s).

Because we did not expect communication to be that frequent, we had no formalized way of handling communication between agents at first. However, after it became clear that communication actually was an integral part of the system, we formalized the communications by adding labels to all possible communications and implementing functions to catch unrecognized communications.

The second underestimated issue was with regard to the amount of agents. The first steps in implementation were performed with a handful of different agents. Later, when we scaled up the agent population to the amount of agents we would ultimately use in our simulations, error handling became quite difficult. With the amount of agents increasing, the amount of communications also increased. Tracing faulty communications back to the source became almost impossible.

In order to combat this issue we implemented a logging mechanism for each agent. All relevant communiques and decisions were now logged by the agents. This made tracing errors a lot easier. The downside of the extensiveness of the logging was the incredible size of the log data files: next to the actual results of our simulation 1.43 gigabytes of logging data was generated.

Because of these difficulties, we had to ajust our goals with the simulation. Initially, we intended to run the simulations on a larger scale and based on real data. We also considered having evaluation sessions (perhaps through a serious game) with the sector, to validate the prototype. However, because completing the first version of the prototype took a lot more time than initially expected and because of time limitations of this research, we were unable to do these things.

Therefore, we chose to run the simulations on a smaller scale, with (partially) simulated data. We attempted to adjust the parameters of the simulations to represent the actual situation as accurate as possible. We were however unable to validate these parameter settings.

5.5 Input and output

In figure 10, the input and output of the simulation is displayed. In this section, we will discuss all the inputs of the system.

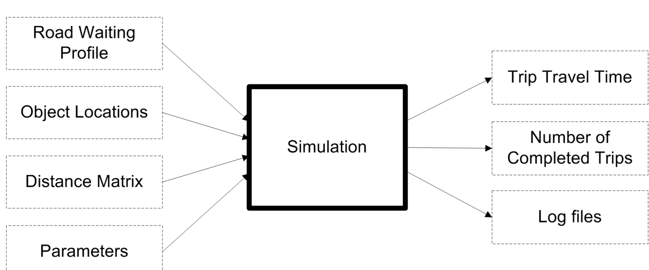

Figure 10: The input and the output of the simulation.

5.5.1 Road waiting profile

The road waiting profile is displayed in figure 11. Depending on the travel moment, the time it takes varies. We implemented this profile to represent traffic business during the peak hours in the morning and late afternoon.

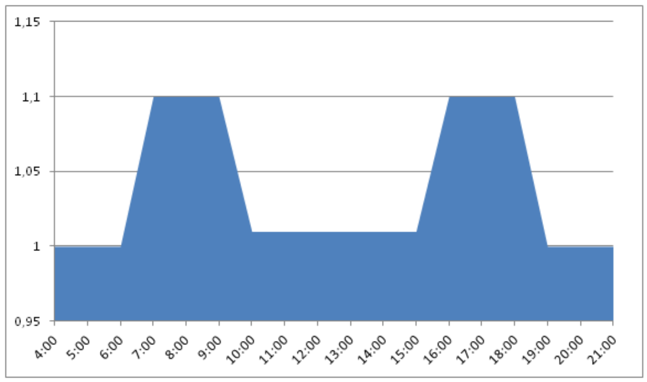

Figure 11: The road waiting profile.

5.5.2 Object locations

Every terminal, customer, truck starting points and depots had to be located somewhere. The inputs we generated for our simulation were Google Maps coordinates, spread out over the Benelux. The terminal and depot coordinates were specifically located in the port of Rotterdam, the other coordinates were randomly selected.

5.5.3 Distance matrix

For route generation, we made use of Google maps. Using an url with specific coordinates embedded, Google maps would return an xml file with the expected travel duration and time. Because only 2500 calls were allowed per day and because a dependency on Internet requests would slow the simulation down, we wrote a program to collect all possible travel durations in a huge table. In the simulation, the transport time estimation agent only had to look up the data in this table.

```
http://maps.googleapis.com/maps/api/distancematrix/
xml?origins=|51.59,4.8&destinations=|53.22,6.6&mode=
driving&language=nl-NL&sensor=false
```

An example of a xml-file-request url.

5.5.4 Parameters

In this section the parameters that were chosen for the experiments will be discussed. Each of the following subsections will deal with a specific category of parameters. In table 11, the entire parameter list is displayed.

Agent amounts

The amount of agents used was limited by several factors:

- Limited computational power.
- JADE limitations.
- Limited Google maps requests.
- Time restrictions.

In order to find significant results, the goal was to perform many simulations. Therefore, the simulation speed was 60 times normal speed. This together with the total amount of agents made the simulation very memory and CPU intensive. On top of that we experienced some difficulty with JADE (the Java toolkit used) in handling a large number of agents (random crashes and memory leaks among others).

Another reason to limit the amount of agents was because Google maps limits the amount of location requests per day (2500). Therefore, there was a practical limitation on the amount of locations we could use in the simulation.

Road randomness

The predetermined transport time was calculated using the travel times provided by Google maps (the method of implementation is discussed in section 5.5.3) multiplied by the road waiting profile (section 5.5.1).

Besides this static road waiting profile, which considers the expected traffic delays, a random varying factor was also included in order to make traveling less predictable. There are two facets to this randomizing: there is a relatively large chance on a small delay or small speed up in travel time and there is a small chance on a larger delay. This delay or small speed up is incorporated in every update on the transport time (which was every minute in-simulation-time).

Customer settings

The desired arrival time is set at least several hours past the current system time. The customer arrival window was set relatively liberal to 4 hours because

Name:	Value:	Description:
Agent amounts:		
Number of terminals:	2	
Number of depots	2	
Number of transport companies	5	
Number of trucks	151	Per transport company, respectively: 50, 50, 25, 25 and 1.
Number of stacks per terminal	6	
Road randomness:		
Road Randomness	0.01	The chance on small randomness on the road.
large delay chance	0.0001	The chance on a large delay.
Time period between delay possibilities	1 min.	
large delay size	5 min.	
Road waiting profile		see figure 11
Customer settings:		
Minimum placement time	180 min.	The time between order placement and desired arrival time.
Maximum placement time	840 min.	
Customer arrival window	240 min.	
Time settings:		
Container switch time	15 min.	Amount of time before the expected ETA at the terminal a container switch is considered.
Time-slot length	60 min.	
Beginning of a day	04:00	Starting moment of a day.
End of a day	21:00	Ending moment of a day.
Simulation time	×60	60 times normal time
Minimum process times:		
Terminal process time	15 min.	The minimum process time of a truck at a location.
Stack process time	5 min.	
Customer process time	15 min.	
Depot process time	15 min.	
Other:		
Number of orders per truck	×2	Number of orders for a transport company per truck
Deviation of order types	50-50	

Table 11: The parameters.

we wanted to figure out whether or not the main idea behind container switches are useful without being restricted too much by this parameter.

When the best possible departure time (with regard to travel time) is selected, this value is used as a requirement for the expected arrival time. The goal is to have the shortest possible arrival time, while still arriving within the set customer window.

When no specific departure time is chosen but immediate departure is opted for instead, this value is not relevant. The underlying assumption here is that customers especially worry about delivery being late. Trucks are in both cases handled in order of desired arrival time. In case no specific departure time is chosen, trucks depart immediately and will arrive at the customers as soon as possible.

Time settings

Because stack waiting times are considered to be useful only when a truck is near the terminal, we set the moment for a container switch to 15 minutes before expected arrival.

We wanted the amount of time slots not to be too large and also not too small. We therefore chose for the convenience of having one time slot per hour. Too large time slots would make scheduling using time slots less useful because with less time slots, the actual arrival times of trucks (and thus the business) are more difficult to determine. With too small time slots, there would be a large amount of different time slots, and the arrival time of a truck within a specific time slot is more uncertain. Still, choosing one hour time slots still is quite arbitrary. We did not have the time and resources to investigate the time slot size in more detail.

The start and end time of the day were based on the situation in the field: trucks rarely drive at night.

Minimum process times

The process times on the terminal and stack are based on our visit to the Euromax terminal. It is assumed, since the same process takes place, that the same time is required at the customer and at the depot. Because the time at the customer and depot are not the focus of this study and are static throughout the simulation, these values are less relevant.

Other

The amount of orders a truck company is given to process was set on 2 times the number of trucks the transport company has. This is based on the idea that ideally, a truck performs two trips a day.

The distribution of order types was 50-50: 50% of the time a truck needed to pick up a container at the terminal, and the other 50% of the time, the truck first needed to pick up a container at the customer.

5.5.5 Output

The simulation generated several different outputs. First off, every agent generated log-files with detailed information on what communications the agent receives and sends, what information the agent processes and what decisions the agent makes. Secondly, the data required for our experiments was generated: trip time and trip completions. Beside the total trip times, the trip times of parts of the trip (for example from the terminal to the customer) were documented, together with the trip details.

5.6 Design

In the design of this experiment, there are 2 dependent and 2 independent variables:

Dependent variable 1:	=	Trip time.
Dependent variable 2:	=	Amount of trips per day (quantitative).
Between-subject factor A	=	Making use of waiting profiles for deciding departure time (yes/no)
Between-subject factor B	=	Making use of container switching (yes/no)

The between subject factors result in four groups. These groups are displayed in table 12. This experiment was a between factor experiment: every new order was generated randomly.

	Container Switch	Waiting Profiles
Between subject group 1:	No	No
Between subject group 2:	Yes	No
Between subject group 3:	No	Yes
Between subject group 4:	Yes	Yes

Table 12: Independent variables.

5.7 Results

In this section we discuss the results of our experiments. In subsection 5.7.1, we discuss the effects of the use of waiting profiles for deciding departure time (in this section abbreviated with using waiting profiles) and container switches on travel time. In subsection 5.7.2, we discuss the effect of the same factors on the amount of performed trips per day. The elementary reports of the ANOVAs can be found in appendix B.3.

5.7.1 Effect of container switches and waiting profiles on trip time

In table 13, the data of the different test groups is displayed. Figure 12 shows the averages. Using waiting profiles seems beneficial (778 as opposed to 660 minutes), and making use of container switches does not seem to have a big impact: 706 as opposed to 746 minutes.

An important observation is the large standard deviations: this implies skewed data, especially in the CS(yes)&WP(no) group. The data spread is displayed in figure 13. The travel times when no waiting profiles are used seem to "lean" more to the right. Furthermore, the normal distribution is more or less "cut off" after a 1000 minutes: there are almost no instances in this category.

	WP(no)	WP(yes)	
CS(no)	μ = 741.42	μ = 667.80	μ = 706.24
	σ = 181.39	σ = 186.67	
	n = 1783	n = 1632	
CS(yes)	μ = 824.92	μ = 649.07	μ = 745.62
	σ = 382.43	σ = 159.18	
	n = 1406	n = 1155	
	μ = 778.24	μ = 660.04	μ = 723.11

Table 13: Average (in minutes), standard deviations and n of trip times.

Analysis of variance

A 2 factor-ANOVA was performed with trip time (in minutes) as the dependent variable and container switching (yes, no) and waiting profiles (yes, no) as the independent variables. The results show the following:

- There is a significant effect of the factor container switch on travel time ($F(1,5972) = 25.97$, p=.000). The group with container switching has a longer trip time. This effect is weak (eta^2=.004).

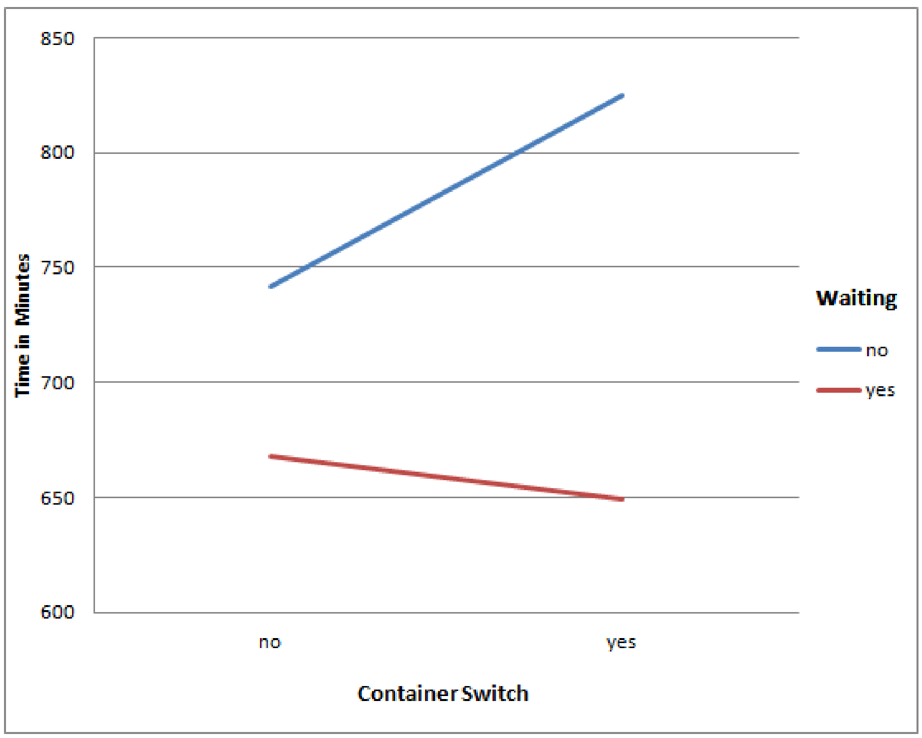

Figure 12: Amount of fulfilled orders.

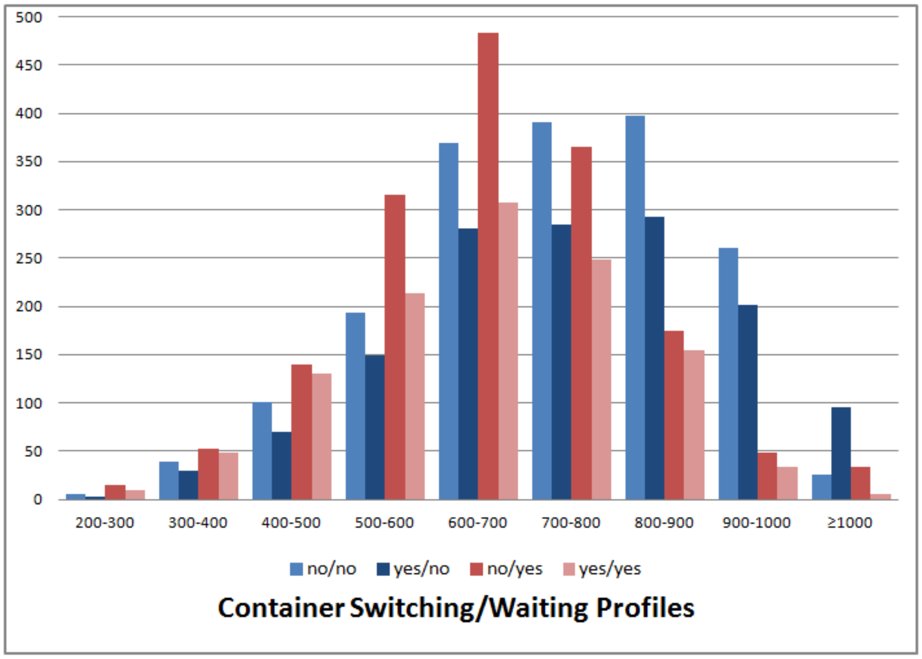

Figure 13: Travel time data spread.

- There is a significant effect of the factor waiting profile on travel time (F(1,5972) = 385.16, p=.000). The group with waiting profiles has a shorter trip time. This effect is weak (eta^2=.061).
- There is interaction between the factors container switch and travel time (F(1,5972) = 64.67, p=.000). This effect is weak (eta^2=.011).

Non-parametric tests

Because the aggregated data shows a potential violation of the homogeneity of variances, an ANOVA may show incorrect results. Therefore, we also performed the non-parametric Mann-Whitney U-test to confirm the in the ANOVA found results. These show the following:

- There is no significant effect of the factor container switch on travel time (p=.156).
- There is a significant effect of the factor waiting profile on travel time (p=.000). The group with waiting profiles has a shorter trip time.

Because no significant effect was found in the non-parametric test with regard to container switching and because the ANOVA results are unreliable, we conclude that there is no significant effect with regard to container switching.

Comparing the four different groups

Because of the interaction between the factors waiting profile and container switching, the obtained results may not tell the whole story. Therefore, we performed several 1-factor ANOVAs to investigate the differences between the 4 different groups. The results are the following:

- The group without container switching and without waiting profiles differs significantly from the group with container switching and without waiting profiles (F(1,3188)=66.07, p=.000). The group with container switching and without waiting profiles has a longer trip time. This effect is weak ($eta^2 = .02$).
- The group without container switching and with waiting profiles does differ significantly from the group with container switching and with waiting profiles (F(1,2786)=7.64, p=.006). The group with container switching and with waiting profiles has a longer trip time. This effect is weak ($eta^2 = .00$).
- The group without container switching and without waiting profiles differs significantly from the group without container switching and with waiting profiles (F(1,3414)=136.235), p=.000). The group without container switching and with waiting profiles has a shorter trip time. This effect is weak ($eta^2 = .04$).
- The group with container switching and without waiting profiles differs significantly from the group with container switching and with waiting profiles (F(1,2560)=213.41, p=.000). The group with container switching and with waiting profiles has a shorter trip time. This effect is weak ($eta^2 = .077$).

Because the aggregated data shows a potential violation of the homogeneity of variances, an ANOVA may show incorrect results. Therefore, we also performed the non-parametric Mann-Whitney U-test to confirm the in the ANOVA found results. These show the same results:

- The group without container switching and without waiting profiles differs significantly from the group with container switching and without waiting profiles (p=.005). The group with container switching and without waiting profiles has a longer trip time.
- The group without container switching and with waiting profiles does not differ significantly from the group with container switching and with waiting profiles (p=.141).
- The group without container switching and without waiting profiles differs significantly from the group without container switching and with waiting profiles (p=.000). The group without container switching and with waiting profiles has a shorter trip time.

- The group with container switching and without waiting profiles differs significantly from the group with container switching and with waiting profiles (p=.000). The group with container switching and with waiting profiles has a shorter trip time.

Although with regard to the group without container switching and with waiting profiles and the group with container switching and with waiting profiles, a significant effect was found with the ANOVA (p=.006). Such an effect was not found with the non-parametric test (p=.141). Because the ANOVA tests are unreliable, we have to conclude no effect was found.

Summary

- There is a significant benefit to using waiting profiles to decide departure time.
- Although a significant benefit to using container switching and waiting profiles compared to no container switching and using waiting profiles was found with the ANOVA, there is no effect found in the non-parametric test. Because of the unreliability of the ANOVA, we have to conclude there is no effect.
- There is a significant loss in using container switching without waiting profiles compared to not using waiting profiles and not using container switching.

5.7.2 Effect of container switches and waiting profiles on the amount of completed orders

In table 14, the data of the different test groups are shown. Figure 14 shows the averages. Using waiting profiles seems detrimental (96 as opposed to 114 completed trips), and making use of container switches does not seem to have a big impact: 102 as opposed to 107 completed trips.

An important observation is the large standard deviations: this implies a very skewed data. This can be seen as well in figure 15.

Analysis of Variance

A 2 factor-ANOVA was performed with the amount of completed orders (per day) as the dependent variable, container switch (yes, no) and waiting profiles (yes, no) as the independent variables. The results show the following:

- There is no significant effect of the factor container switch on the amount of completed orders ($F(1,53) = 1.712$, p=.196).

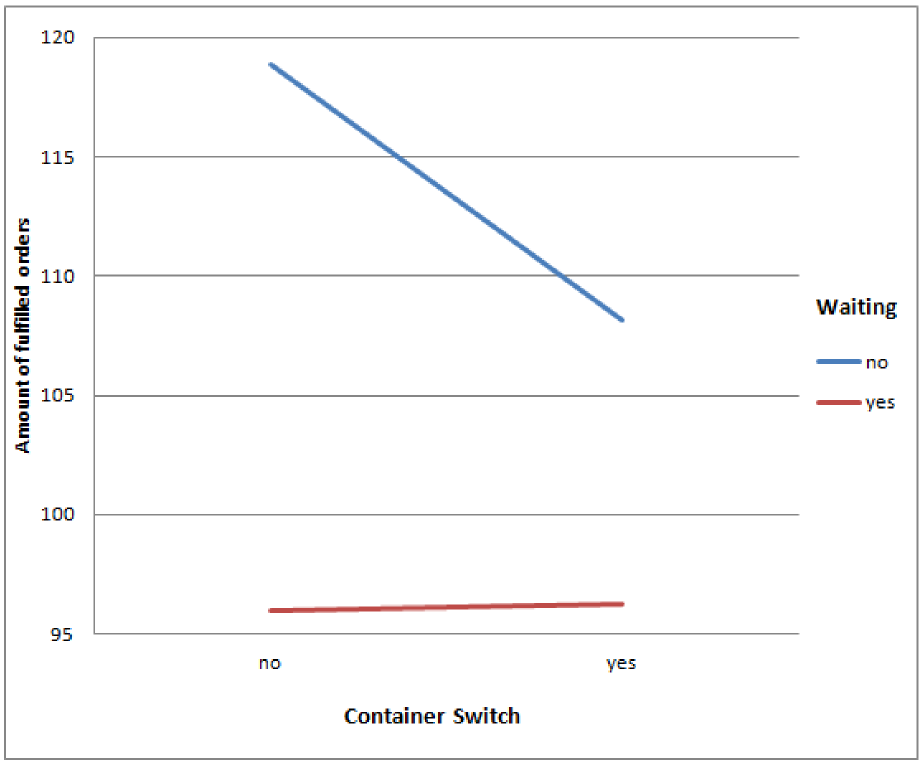

Figure 14: Amount of fulfilled orders.

	WP(no)	WP(yes)	
CS(no)	$\mu = 118.87$	$\mu = 96.00$	$\mu = 106.72$
	$\sigma = 14.09$	$\sigma = 16.36$	
	$n = 15$	$n = 17$	
CS(yes)	$\mu = 108.15$	$\mu = 96.25$	$\mu = 102.44$
	$\sigma = 17.24$	$\sigma = 10.58$	
	$n = 13$	$n = 12$	
	$\mu = 113.89$	$\mu = 96.10$	$\mu = 104.84$

Table 14: Average, standard deviations and n for performed trips.

- There is a significant effect of the factor waiting profile on the amount of completed orders (F(1,53) = 18.91, p=.000). The amount of completed orders is decreased when waiting profiles are used. This effect is strong (eta^2=.263).
- There is no interaction between the factors container switch and the amount of completed orders (F(1,53) = 1.88, p=.176).

Because no interaction effect was found, we did not investigate the individual groups in detail.

Non-parametric tests

Because the aggregated data shows a potential violation of the homogeneity of variances, an ANOVA may show incorrect results. Therefore, we also performed the non-parametric Mann-Whitney U-test to confirm the found results in the ANOVA. These show the same results:

- There is no significant effect of the factor container switch on amount of completed orders (p=.130).
- There is a significant effect of the factor waiting profile on the amount of completed orders (p=.001). The amount of completed orders is decreased when waiting profiles are used.

Summary

- There is a significant loss in amount of fulfilled trips when waiting profiles are used to decide on departure time.
- Container switching has no significant effect on the amount of trips performed.
- Although figure 14 seems to show an interaction effect, no such effect is found.

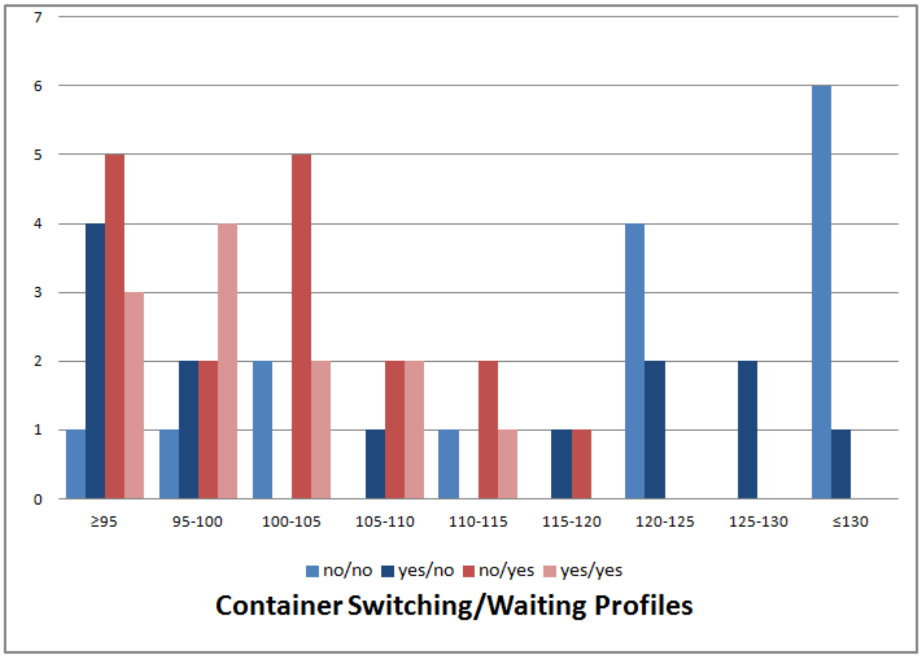

Figure 15: Amount of fulfilled orders data spread.

5.8 Discussion of the results

In this section we interpret the results found in the previous section. In the first subsection we will discuss container switching. In the second subsection waiting profiles will be discussed.

5.8.1 Container switching

One of the most surprising results from the simulation to us was the *increase* in travel time when using container switches without using waiting profiles to spread out truck arrival times. A container switch is only approved when the total estimated travel time of the new situation is less than the current estimated travel time. Apparently, these estimations fail when no waiting profiles are used.

One explanation for these results could be that when no waiting profiles are used to decide the departure time of truck (but the trucks depart immediately upon receiving their order), the peaks at the terminal are a lot higher than with waiting profiles. As can be seen in figure 16 there is definitely a peak in the morning. This can be seen in table 15 as well, where the standard deviation in the number of trucks per hour is a lot higher without waiting

	WP(no)	WP(yes)	
CS(no)	$\mu = 12.83$ $\sigma = 12.94$ $n = 15$	$\mu = 11.43$ $\sigma = 3.88$ $n = 15$	$\mu = 12.13$
CS(yes)	$\mu = 13.80$ $\sigma = 13.36$ $n = 15$	$\mu = 12.52$ $\sigma = 4.43$ $n = 15$	$\mu = 13.16$
	$\mu = 13.32$	$\mu = 11.98$	$\mu = 12.65$

Table 15: Aggregated data on the mount of trucks arriving at the terminal per hour (for all days).

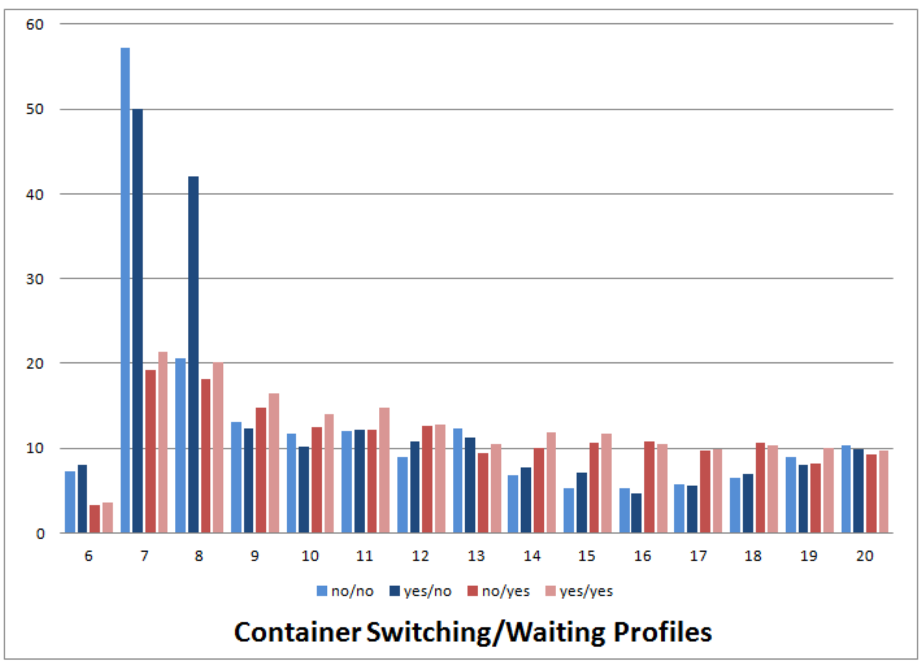

Figure 16: The amount of trucks arriving at the terminal per hour.

profiles. During these peaks at the terminal, there will be a lot of trucks arriving at the same stacks at more or less the same time. As can be seen in table 16, there are seemingly (not significantly: $p = 0.162$) more container switches per day when waiting profiles are not used as compared to when waiting profiles are used.

	WP(no)	WP(yes)	
CS(yes)	$\mu = 12.31$	$\mu = 8.67$	$\mu = 10.56$
	$\sigma = 5.74$	$\sigma = 6.84$	
	$n = 13$	$n = 12$	

Table 16: Average number of container switches per day.

These switches are performed without taking into account the other switches performed at the same time. This will actually result in a 'swarming' of a previously relatively quiet stack, resulting in an actual increased stack waiting time instead of the estimated decrease. This effect is demonstrated in table 17.

	Stack:		
	1	2	3
Before Container switch:	6	2	6
After Container Switch:	2	10	2

Table 17: Division of trucks before and after a number of simultaneous container switches. "Everyone" moves to the (previously) quiet stack 2 at the same time.

If the truck arrivals are spread out over the day (when waiting profiles for deciding departure time are used), this problem of simultaneous switching occurs less, which at least balances out this negative side-effect. Although figure 12 even shows a decrease in trip time when container switching is used in addition to waiting profiles, the obtained results were not significant in the non-parametric test.

These results show limitations to the simulator. In order to perform a container switch, a lot of communication is required, as can be seen in figure 17. We found communication to be relatively slow compared to the simulation speed (60 times normal time). There is a significant delay between the communicated situation and the actual situation. Without the artificial speed increase, this delay will probably have less impact. We feel these results show the importance and difficulties of on the spot provision of actual information. Furthermore it shows problems with regard to syncing communication and simulation speed. We did not expect this problem having such an impact.

A seemingly obvious solution may be to slow down the simulation speed when communication takes place or increase the communication speed with the same pace as the simulation speed. This will probably resolve these difficulties (or

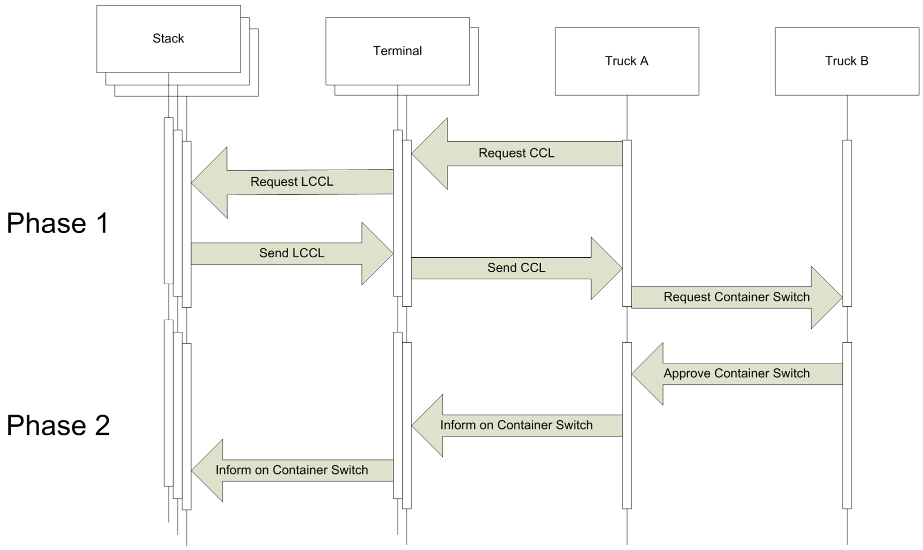

Figure 17: The communications performed for a container switch.

at least to a degree). However, since it took nearly 3 weeks to simulate 57 days in the current setup and a huge amount of data is required in order to get significant results, this simply was not possible due to time limitations. Perhaps another agent toolkit than JADE will be more suitable for these kinds of simulations.

The conclusion that has to be drawn from these results is that there is not enough evidence to show the benefit of container switching, nor is there enough evidence to reject the use of container switching. When the limitations to the simulation are lifted, perhaps more conclusive evidence can be gathered. When the simultaneous container switches are taken into account, we would expect a significant decrease in travel time. Especially because the test (at least the ANOVA) and the averages suggest a decrease in travel time when waiting profiles are used. More research to confirm this expectation is required.

5.8.2 Waiting profiles

The use of waiting profiles significantly decreases the average travel time. Unfortunately, it also significantly decreases the amount of fulfilled orders per day. This is counter-intuitive. How can a decreased travel time cause the amount of fulfilled orders to decrease?

We think that this is caused by the scheduling of the trucks. When no waiting profiles are used, a truck departs immediately. But when using waiting profiles, the truck delays departure until a suitable expected arrival time can be realized.

This means that, even if their single trip times are shorter, trucks using the waiting profiles might still be finished later and not be able to perform a second trip because the idleness at the start of the day is still larger than the travel time saved. See figure 18 for an example.

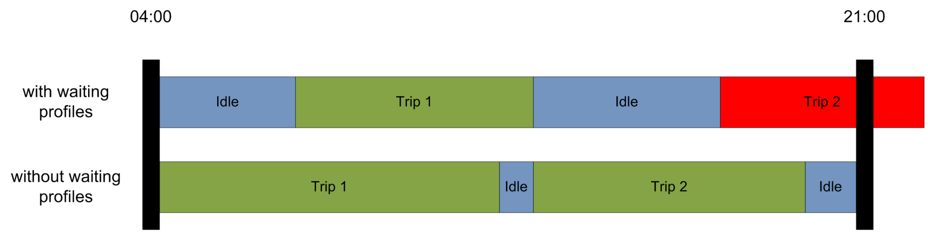

Figure 18: Truck scheduling with and without waiting profiles.

Another explanation can be found in the differences between the with and without waiting profiles groups. In the groups where no waiting profiles are used for departure times, there are no customer requirements used to decide departure time: the trucks always depart immediately. As explained, the assumption here is that an earlier arrival time is not a problem for the customer. However, the absence of this constraint may have its influence on the amount of fulfillable orders, as figure 19 shows.

This makes the comparison somewhat unfair: besides the between subject factor of making use of waiting profiles, the customer arrival window may act as a disturbing variable because it constrains the situation when waiting profiles are used, while it does not constrain (explicitly) the situation where waiting profiles are not used.

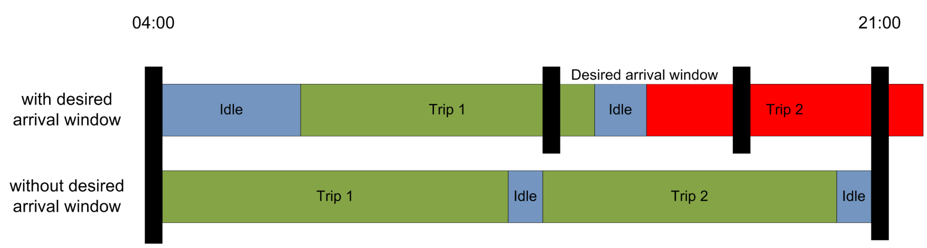

Figure 19: Truck scheduling with and without customer requirements on arrival time.

Based on the results we have, it is not possible to say which of these two explanations fits best. We think that both of these effects exist.

Although this significant decrease in amount of fulfilled orders may be caused by an unfair comparison, we can at least conclude that time windows of customers and/or time limits on when trucks are allowed to drive have a significant impact on the amount of fulfilled orders. Either the limited time windows have to be discarded, or these time windows should be taken into account in decision making. The time windows were specifically implemented because it is a reflection of the current situation in the port. Customer requirements make it unlikely for these windows to change a lot (see the conclusions in section 3.4).

The time window information should be used to decrease the travel times in such a way that is not at the cost of the amount of trips. We think that if orders are assigned to a truck for an entire day, these orders can be scheduled in such a way that the travel time is minimal, while all the orders still are performable. For example, when it is decided that two specific trips should be performed by a specific truck (one in the morning and one in the afternoon), there is "wiggle room" with regard to the planned arrival time of the truck. In this situation, the shortest travel times while meeting customer arrival windows can be found when use is made of waiting profiles.

This would make waiting profiles useful even when limited operating hours are applicable. The interaction between customer arrival windows and waiting profiles should be investigated in more detail.

5.9 Evaluation

The last step in the design science process is evaluation of the work done (see section methodology). There are several types of evaluation that can be performed:

- Evaluation of the results of the prototype.
- Evaluation of the construction of the prototype.
- Evaluation of the validity of the prototype.

In section 5.8 the results from the simulation are discussed. In the next subsection (section 5.9.1) we will focus on an evaluation of the construction of the prototype. Initially, we were planning on an expert review by experts in the transport sector on the validity of the prototype. However, due to time limitations we were unable to do so. We were able to present our research to several Artificial Intelligence experts. The issues these experts brought up are discussed in section 5.9.2.

5.9.1 Construction of the prototype

Given the results from our simulation, we are satisfied with the significant results on decreasing waiting time. However, given several programming difficulties we feel the results could have been better and more relevant than what we ultimately acquired. The following parts of the simulation could have been better:

- Container switches should not be blind to other simultaneous container switches.
- The run time of the simulation should not influence simulation results.
- Arrival requirements should be the same for all in-between groups.

We did not expect (the sizable effect of) these problems, claiming these were mistakes to be avoided is easy in hindsight. We think the problems that surfaced tell us more about (the trouble with) simulating and what issues may arise. This may help in avoiding these kinds of problems in the future. We feel one of the more important results we found is that building simulations is more difficult than we expected, and certainly more work with regard to this needs to be done before an actual implementation should be attempted.

While working on a simulation for more than half a year, several weaknesses to simulating in general have become clear. Especially with regard to the more complicated computational models, like truck container time slotting, we feel the simulation may not be as representative of the actual situation as we would have liked.

For one, modeling a complicated problem, requires on the one hand a simplification of reality and on the other hand a complicated model. Simplifying reality can lead to the leaving out of important aspects, while making the model more complicated is prone to lead to (more) programming errors.

Because the problem and therefore the model is complicated, it also becomes more difficult to confirm obtained results. Especially if obtaining results takes weeks to months.

Given these issues, and given enough time, it seems to us that it is relatively easy to build a model, and tweak it such that it yields the results that the researcher wants it to yield. Because the models built are complicated, it is at the same time relatively difficult for other researchers to confirm the results.

Given the bias in scientific journals toward positive results (the so called "file drawer problem"; Rosenthal,1979) and given potential powerful parties with an invested interest, this is not a trivial issue. The argument we would use to demonstrate the relevance of our conclusions, is that given the reported results, a bias toward positive results is unfounded because our results are rather mixed.

Interpreting the results of simulation in relation to the validity of the simulation is not a trivial task, and extra care in this aspect should be taken. Retesting earlier found results should be the standard.

5.9.2 Expert evaluation

During a session with artificial intelligence (AI) experts, we presented our work in order to gain feedback from the perspective of AI experts. After the presentations the experts were allowed to ask questions. Because these questions are a reflection on how our work is perceived, we felt it important to answer these questions in more detail in this thesis. By answering these questions, we hope to clarify the goals in this research, and the choices made. In the following subsections we will discuss the questions asked.

Is it not possible for a centralized solution to work more efficiently than a MAS solution?

It may very well be the case that in theory, a centralized solution will yield better global results than a multi-agent system. We did not investigate the optimality of centralized versus multi-agent systems. However, as explained in chapter 1, the goal of this thesis was to propose a practically implementable solution. Because there are many autonomously operating parties in the port currently, we felt it more feasible to get a distributed solution implemented.

Why is the automatization of decision making required? Can't human agents make the decisions?

In this research we propose a multi-agent system with software agents. However, as discussed in chapter 3, decision making in the transport sector, and especially with the transport companies, is done by humans. The questioner argued, that if the relevant information is available, human agents are capable of decision making as well.

We would agree with this. Although we made use of software agents in our simulations, and we generally only referred to software agents as agents, humans are of course agents as well. Given the distributed nature of multi-agent systems, as long as the protocols are universal, every participant is able to implement its own agents. These agents may be software agents, but these can be human agents as well. In our research, we focused on a multi-agent solution for the sharing of travel time estimations. We do not necessarily specify the nature of the agents.

Other means of transport are also possible in the port. How does that relate to your research?

In our research we focused on truck transport. Of course, as we discussed in chapter 1, there are also other means of transport: transport by barge or by train.

Although we did not perform research on this topic specifically, there is a trend in the transport sector in the direction of "synchromodality". Synchromodality essentially means that the means of transport is decided on the transfer location, based on the current travel time estimations of the different modalities.

Although we did not research this direction, an extension to our prototype could include information sharing with regard to barge and train transport time estimations. We feel that the push toward synchromodality does demonstrate again the relevance and great use travel time information sharing can have for the transport sector.

What is the relation between the terminal and the transport companies? Who is making the decisions?

In our research we had the requirement that the distribution of decision making power is not changed by implementation of the multi-agent system. Therefore, the transport company remains in control on which container is picked up when at the terminal.

However, the terminal can influence this decision making by providing the transport company with information on the stack waiting times: the terminal can effectively suggest the transport company to pick up a different container than initially intended. This may influence the decisions the transport companies make, but the actual decision power remains with the terminal.

Can local optimization for container switching lead to a global less optimal situation?

As is noted in chapter 5, the results show an increase in waiting time when container switching is performed. During the questions another explanation than the one presented in the discussion of the results was proposed. The questioner wondered whether the decrease in optimality may be caused due to the fact that although container switching may optimize locally, it does not globally.

We think the explanation as given in chapter 5 explains the found results and is also supported by the fact that there is an interaction effect with using waiting profiles. However, we did not rule out the possibility that local optimization by using container switching actually has a negative global impact. More research to confirm or reject this hypothesis is required.

Chapter 6

Conclusion and Discussion

In this thesis we performed several experiments. In section 6.1 we answer the research subquestions. Consequently, we attempt to answer the main research question and relate the (potential) consequences of the results to the performed field research. In section 6.2, suggestions for further research are done.

6.1 Conclusion

6.1.1 Answers to the research questions

RQ1: Are multi-agent systems applicable to the situation in the port of Rotterdam?

Based on the conclusions in our literature study we can say that multi-agent systems seem applicable to highly distributed solutions such as the transport sector. Based on the field study, we can safely conclude that the port of Rotterdam is a highly distributed situation and that therefore multi-agent systems are applicable. However, given the results we obtained from the simulation, the answer to this research question is less straight forward.

The results we obtained showed some promising results, but the results mostly showed that more simulations are required. Our simulation has its limitations, and because of these limitations the results are less clear.

Therefore, based on our literature study, we conclude that multi-agent systems are applicable to the situation in the port of Rotterdam, with the side note that more research in the actual implementation of a multi-agent system is required.

Furthermore, we do not exclude the possibility that a centralized solution could be applicable as well.

RQ2: What can be learned from earlier MAS implementations?

In chapter 2.1.2, we concluded that earlier implementations of multi-agent systems were mostly "stuck" in the simulation phase. We concluded that this is mostly the case because earlier simulations mostly focused on ideal circumstances, with less considerations for the practicalities.

Now that we have built our own prototype and performed our own simulations, we gained a better understanding of why this is the case. In our attempt of simulating closer to the actual situation, with for example (randomly) varying travel times, we encountered several difficulties. On top of that, even while attempting to simulate more accurately, our prototype has its limitations and simplifications as well.

Although we feel our prototype is a step forward exactly because of the emphasis of modeling the current situation, still a lot of work has to be done in simulation before practical implementation should be attempted. That is what we have learned from earlier research and our MAS implementation.

RQ3: What are the current problems in truck transport?

Besides the perhaps more structural and fundamental problems within the sector, where the transport companies are "caught" in between the terminal and the customers, the most important issue seems to be the lack of information sharing between the different parties. In our simulation, we gathered evidence that the sharing of arrival times of trucks is actually useful information with regard to decision making: travel time can be reduced.

RQ4: Which party can facilitate further steps in the implementation process?

Because the results of our simulations are quite limited, we do not think further steps are appropriate at this point: more research with simulations is required before actual implementation is attempted. In chapter 3, we concluded that the port authority should facilitate the implementation process by getting the different parties around the table. We think it should be the port authority because it is the only party with the efficiency of the complete port as its goal and because it is a party with the means to actually be able to facilitate such a process, as is demonstrated by the start up of Portbase.

RQ5: What kind of agent system in what form would fit container transport in its current form?

In chapter 4 we made several design decisions with regard to our multi-agent system. However, as said before, we think more research into multi-agent simulation is required before we can make definitive statements to answer the research question.

However, given the current situation in the port, and given the fact that the results from our simulation show at least some promising results, we think that the design decisions with regard to implicit negotiation and time slotting through waiting profiles were correct. However, more detailed simulation and research is required to confirm this.

RQ6: Do the suggested improvements actually decrease waiting time?

The results with regard to waiting profiles answer this question with a "yes". The results with regard to container switching answer this question with a "maybe". Our simulations show some promising results. Results that warrant further research in using multi-agent systems, container switching and waiting profiles, but do not give a definitive answer to the research question.

6.1.2 Relating the simulation results to the field research results

Given the answers or partial answers to the research subquestions in the previous section, we now turn to the main goal and research question. In section 1.1 we stated that the goal of the research was to:

> *Build a Multi-Agent truck time slotting proof of concept for terminals in the port of Rotterdam in order to demonstrate the use of information sharing for decreasing the total travel time.*

We noted that this research was intended to be a first step toward actual implementation. The solution would be an improvement to the current system, not a proposal for a new system or a new way of doing things. We chose this direction because application of big changes to the system seemed unfeasible. With this goal in mind, we tried to answer the following research question:

> *How can information sharing regarding expected waiting times help in actually decreasing waiting times?*

In section 3.4, we concluded that the current system is stuck at the worst position of a complicated prisoners dilemma. Seemingly simple changes (such as driving at night, or changing the transport business model) would be able to improve the system as a whole but are blocked because these changes would yield losses for some (powerful) stakeholders.

Given these limitations, we built a multi-agent system modeling the current situation, together with suggestions for improvements with regard to information sharing in order to allow the transport companies to make better decisions. The improvements we chose to test were based on the suggestions made by several parties in the transport sector (see section 3.4.3). These improvements were supposed to decrease travel and waiting time.

In section 5.8.2, we concluded that the benefits of waiting time with these improvements do decrease travel time. However, we also concluded that in planning of a trip, the subsequent trip(s) should also be considered in order to prevent a decrease in performable trips per day. We did not find enough evidence to be able to state that container switching has a positive benefit to travel time.

Although the generalizability of our conclusions may be in question, and we definitely agree more research to confirm these conclusions is required, we think that given the results, we can state that using waiting profiles do decrease travel time, and that container switching has the potential to. The question remains whether these solutions are implementable and profitable to implement.

We would recommend further simulation before actual implementation, in order to prevent implementation of a system that does not work. Once the results are conclusive in simulation, the costs and benefits of actual implementation can be researched.

6.1.3 Practical implications

The results from the simulation show in our opinion enough promise to investigate the use of multi-agent systems in order to decrease waiting times in more detail. With regard to practical implementation, we now have some evidence that shows waiting times actually can be decreased without fundamentally changing the current situation.

Before practical implementation can be considered, several steps first have to be taken. First, we would recommend further studies to confirm and/or strengthen our results. For example, we found some evidence that container switching is effective, but before implementation is attempted, more evidence to show that this is the case is required.

Secondly, we would recommend a proper cost-benefit analysis for implementation. Although we found a benefit in reduced waiting times, the question remains whether or not this benefit is profitable enough to warrant the implementation of a multi-agent system for truck time slotting.

Thirdly, enough support for implementation in the sector needs to be acquired. As we concluded in chapter 3, at least some of the transport companies seem to be conservative. Without a broad support from the sector, implementation will probably not yield the desired results.

In conclusion, a lot of work still needs to be done before implementation can take place. As concluded in section 3.4.4, we recommend the Port Authority to take initiative in this effort. However, as explained, more simulation is required before further steps can be taken.

6.2 Suggestions for further research

6.2.1 Further testing

As explained before, given the limited amount of time available and the relative large amount of time required to simulate, the gathering of data was limited. Given the simulation, there are several other aspects that are open to investigation (on top of retesting the results found in this thesis):

- The effects of container switching in a simulation that would have run at a slower pace.
- The effect of container switching (in a lower speed simulation) on larger and smaller transport companies.
- The effect of container switching and waiting profiles in a larger scale simulation (with more terminals, transport companies, trucks and customers).
- The effect of container switching and waiting profiles in a larger time frame, for example a 24 hour economy.
- Basing the input data of the simulation on real data would also greatly improve the simulation results' reliability.
- Investigate the effect of customer arrival windows.

6.2.2 Possible simulation improvements

The built simulation could be improved in several aspects. For one, solving the conflict between speeding up the simulation process and communication speed would greatly improve the testing possibilities of the simulation.

Another benefit to the simulation would be a more realistic truck assignment of transport companies. The model would be more realistic when this assignment is in line with how planners currently assign trucks. Especially because when scheduling of trucks for entire days instead of trips is performed, the problems with regard of amount of completable trips would decrease or even disappear. Simulating stack placement of the terminal that is based on reality (and perhaps even simulate possible improvements in this regard) would also be useful.

An interesting observation is the discrepancy between the actual peaks in the port and the observed peaks in the simulation. In the port, the peaks in traffic are presumed to be in the morning and late afternoon. However, in the simulation, we were only able to recreate the peak in the morning, as figure 16 shows.

These results are explained by the average trip times: on average the trip times are between 10 and 12 hours. With the limited time window in place, many trucks were not able to perform a second trip. In further research, we would suggest to reduce the distances between locations in the simulation, in order to decrease average trip time. In this way, the second peak in the afternoon may be recreated as well.

Other improvements to the current simulation could be the following:

- Intelligent placement of containers in stacks by the terminal.
- Simulate customer involvement.
- Simulate ship arrivals and container placements in stacks.
- Simulate (the maximum) truck driver hours.

6.2.3 Cost-benefit analysis

We concluded that waiting profiles are useful. As explained before, with regard to actual implementation, we think this conclusion is too vague.

The only criterion used in this thesis is (saved) travel time. The question remains whether enough travel time is saved to justify the costs for implementing the multi-agent system. Other indicators, like CO_2 output, personnel cost, noise output and customer satisfaction should be considered in a cost benefit analysis beside travel time.

6.2.4 Expert review

As was noted in section 5.9, we were unable to perform a proper evaluation of the validity of the built prototype. Although we based our design process on the actual situation in the Rotterdam port, our prototype was not evaluated by experts from the sector on its usability and validity. We feel this is a necessary step in the design science process. Unfortunately, due to time restrictions, we were unable to perform this necessary step. Further research needs to be performed on the validity of our prototype.

6.2.5 Learning agents

In dealing with unreliable, ever changing information, perhaps a more intelligent kind of agent is required. It could very well be that a learning agent will be capable of recognizing patterns in the data that humans are unable to detect. Also, given a dynamic environment with several different kind of agents, individual learning agents will be able to take on specific roles, which are not predetermined by the builder of the simulation.

6.3 Recommendations to Logica

With regard to multi-agent truck time slotting, the next step in the process is as I recommended in the previous section: more research into prototyping. However, Logica does not have a research department. On top of that, the only part where research is performed, the graduation program Working Tomorrow, is (almost) shut down. In the last year I worked at Logica, there were several reorganizations and about 10% of the staff was fired. In the near future, Logica will probably be taken over by CGI.

The current focus within Logica is on the short term, with a heavy emphasis on lowering the idleness of employees and increasing profit. With this chosen direction, Logica should not pursue an agent time slotting solution, because such a solution would still require significant research.

It seems to me that Logica has, and will have difficulty in distinguishing themselves from competition. There are little to no investments in new knowledge (no R&D). Knowledge management within Logica is poor in my (and other peoples) experience. Investments in personnel is lacking as well, there is almost no possibility for training and team building events are rare. I was "part" of the practice Business Consulting, but I never met any of the members beside my supervisors and the manager.

I do not think the current direction is the right one for Logica. Investments in the knowledge of the company in general or personnel in specific is essential. Knowledge is the only asset Logica has. And in a rapidly changing market, knowledge will decline without significant investments.

It seems to me that either Logica has to invest in acquiring knowledge by (more) investments in employee training and/or performing some sort of research, or Logica should focus on attracting new knowledgeable employees. Continuing Working Tomorrow, perhaps with a heavier focus on university students (and a smaller emphasis on recruitment), would help as well in maintaining connections with current research at universities.

6.4 Closing words

In this thesis we intended to provide the transport sector in the port of Rotterdam with viable and relatively easily implementable improvements to the truck container transport sector. As it turns out, the viability and the implementability are not as easy to demonstrate as we expected. Dismissing the criticisms from transport companies as conservatism was done relatively easy, but as it turns out, they were partly right.

The simulations demonstrated a positive effect of intelligently using information. Bridging the gap between theory and practice is difficult, but not impossible. We hope that this thesis will guide others in the right direction.

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Appendices

Appendix A

Field research

A.1 A visit to the Euromax terminal

Subject

Discussion of truck time slotting at ECT (plus a tour around the facility that was not a tour at all, because ECT does not provide tours).

Attendees

Hans Moonen (Logica), Johan Hoekwater (ECT), Maarten-Jan van Gool (Logica/RU).

Authors of this piece

Hans Moonen and Maarten-Jan van Gool

Date

18th of August, 2011.

A.1.1 Terminal overview

- The terminal is not as old fashioned as I imagined; trucks that make it inside the gate are handled very fast, almost every part of moving the containers is automated (even with robotic trucks driving around!).

- Robotic Truck = agv (automatic guided vehicle): first terminal in Rotterdam where this was applied is the ECT Delta Terminal, since the 1980s.
- This specific terminal has a dock length of 1.5 kilometers. Theyre planning to extend it to 4 kilometers.
- 3 barge-feeder-cranes // 8 deep-sea-cranes // 27 container stacks // each stack two stacking-cranes: one sea facing, one land facing // two cranes for the train terminal.
- Euromax has world class truck handling: fastest turnaround times in Rotterdam (according to Hoekwater).

A.1.2 Terminal plans

- ECT has plans to shave off the peeks of rush hours of the trucks.
- The terminal is planning on building their own system in which especially the truck container coupling should be made less strict. Portbase Road planning: no longer truck + driver + container# specified, but just a list of containers (perhaps not even specific container numbers, but only the carrier name (like Cosco)).
- It should be a flexible solution, but eventually the system should be enforced. Hoekwater was not sure about a gradual change towards a more enforced system, or a sudden change to a strict system.
- Trucks should decide on availability and ease of transport which specific container they will pick up on arrival at the terminal.

A.1.3 Terminal considerations

- Hoekwater does not really see the benefits of a large scale project with lots of partners involved. He thinks if everyone has a say, nothing will happen eventually.
- On the other hand ECT is not willing to take the wheel and do the dirty work for their competitors.
- ECT is not willing to pay for services like port base.
- Although ECT does not plan to work with TLN/TNO/Logica/Ortec, but their plans seem compatible with ours. Hoekwater is interested in getting up-to-date on our plans and further developments.
- Hoekwater showed his concern for the smaller truck companies multiple times. A solution to congestion problems should not be at the cost of the smaller companies.

- The havenbedrijf, according to Hoekwater, is split on how to proceed in optimizing port operations. On the one hand they seem to think that by competing companies are forced to improve. On the other hand, when competing leads to an overall inefficient solution, the havenbedrijf wants companies to work together.

A.1.4 Causes of delay

- According to Hoekwater, its not the terminal that is the cause of congestion. The problem is the delivery in the hinterlands (and the timeslots for delivery requested by the hinterland).
- Providing/sharing information seems key. The terminal could do a whole lot with accurate(!) information from the trucks and truck drivers. At the moment, about 60% of the information the terminal gets from the trucks is incorrect.
- The truck drivers could put the container on the truck themselves, but they are not allowed because of union rules. ECT especially has to hire personnel to walk around and put the container on the truck. This (can also) cause(s) additional delays.
- Delays at the terminal arrive when trucks do come for containers which are stacked in the same stacking-lane. Handling time at the stack is something like 10 minutes max. But queues exist for peak situations (overall crowded, but also trucks for same stack)

A.2 Slot management in container trucking

Attendees

Wout vd Heuvel (TLN), Arnoud Kuiper (Ortect), Hans Moonen (Logica), Jeroen Visser (Logica), Maarten-Jan van Gool (Logica/RU), Albert Veenstra (TNO).

Author of this piece

AW Veenstra

Date

18th of August, 2011.

A.2.1 Introduction

Het aankomstproces van vrachtwagens bij container terminals in havens staat al jaren onder de aandacht. In dit aankomstproces zitten pieken (in de ochtend, en in de late middag), waardoor wachttijden voor en op de terminals oplopen, en waardoor de efficiency van het afhalen van containers onder druk staat. De redenen voor de pieken zijn divers, maar een van de belangrijkste is het planningsproces van de wegvervoerders, waarin s ochtends uithalen van een container, wegbrengen naar de bestemming, een andere ophalen en weer in de haven afleveren een normaal patroon is. Dat neemt niet weg dat er wel flexibiliteit in dat patroon zit.

Een factor die het aanpakken van dit probleem bemoeilijkt is dat er geen formele relatie is tussen de terminals en de wegvervoerders. Hierdoor hebben de terminals geen directe reden om de wachttijden van de vrachtwagens te bekorten, tenzij het uit de hand loopt en er zichtbaar een probleem is. Terminals, althans in rotterdam, zijn daarom ook altijd terughoudend geweest in het installeren van slot-management-oplossingen, terwijl hiervoor in de afgelopen 15 jaar een hele reeks projecten zijn gedefinieerd en uitgevoerd. Dit betekent niet dat er niets is in termen van informatievoorziening tussen terminals en trucks , maar een systeem om de piekbelasting te beheersen is er niet.

A.2.2 Doel van deze werksessie

Het ontwikkelen van een virtueel slotmanagement systeem voor container trucking, dat is gebaseerd op beschikbare informatie over het wegvervoer. Een belangrijke voorwaarden voor enig systeem is dat het dynamisch moet zijn in de zin dat veranderingen onderweg doorgevoerd moeten kunnen worden in aanpassingen aan de planning bij zowel wegvervoerder en terminal.

A.2.3 Basisidee

Het basis idee is om de beheersing van de pieken niet van de terminal te laten komen, maar van de wegvervoerders zelf. Hiervoor is een combinatie van informatie nodig over planning, locatie van wagens, en verkeersintensiteit met de truck planningsindicatoren in Portbase, en een intelligente dynamische slotuitwisselingsoplossing.

Op basis van deze informatiecombinatie kunnen aankomstprojecties gemaakt worden voor de verschillende terminals, waarmee de terminals precieser genformeerd worden over de pieken, en daardoor beter kunnen anticiperen op die pieken en de planning van activiteiten op de terminal.

De oplossing kan in fasen worden ontwikkeld, waarbij eerst de informatie gekoppeld wordt, en later de dynamische uitwisseling van containers over trucks kan worden ontwikkeld. In een derde fase kan tenslotte de container uitwisseling ook gekoppeld worden met de terminal zelf, zodat de terminal ook invloed heeft op welke containers eerst afgevoerd worden, en welke later.

A.2.4 Verwachte impact

Dit systeem behelst de introductie van een nieuw sectorbreed informatiesysteem, waarmee uiteindelijk de efficintie van de containerafhandeling in Rotterdam als geheel efficinter wordt. Dit is meetbaar met variabelen als gemiddelde wachttijd van trucks bij terminals, gemiddeld aantal trucks in het havengebied, vertragingstijd voor trucks op de A15. Effecten zullen ook te zien zijn in efficiencyvariabelen zoals gemiddelde beladingsgraad van trucks, omdat het systeem ook zal helpen met het plannen van containers zodanig dat trucks vol aankomen en vol weer wegrijden.

A.2.5 Uitwerking

De ontwikkeling van dit systeem zal gebaseerd zijn op de combinatie van informatie en technologie die in principe allemaal al bestaat. De uitdaging is meer het ontwikkelen van de integratie van de informatie op een open platform. De basis voor dit platform kan in principe geleverd worden door Portbase, als zij hun nieuwe NLIP ingericht hebben.

De innovatie zit in de koppeling van gegevens (met name in koppelen van planning, locatie en verkeersinformatie zie ook het lopende initatief RITS van de verkeersonderneming), en in het ontwikkelen van de exchange module (maar zie bijvoorbeeld het Paris systeem).

A.2.6 Vervolg

Er zijn verschillende mogelijkheden om dit initatief vorm te geven in een project. Binnen TNO zijn er initiateven waarin bovenstaande als business case goed zou passen. De belangrijkste is het projectvoorstel Demanes, waarin de integratie van sensor netwerken (denk trucks, wegen en terminals) centraal staat. Daarnaast is er een mogelijkheid om met beperkte deelname van bedrijven een subsidietraject op te zetten waarin het ontwikkelwerk kan worden ondergebracht. Binnen Logica en Ortec zijn er ook investeringsmogelijkheden, als bovenstaand in de context van product-ontwikkeling kan worden gebracht. Tenslotte past dit initiatief ook goed in de gedachtelijn van het Topgebied Logistiek.

Een eerste proof of concept kan gebaseerd worden op het RITS 2 project van TNO en ORTEC, waarin reistijdvoorspellingen gekoppeld worden aan planningen van twee wegvervoerders.

Het verdient aanbeveling om over fundingmogelijkheden nog een keer specifiek met elkaar van gedachten te wisselen.

A.3 Deelmarkt AZV een informatieavond over dynamisch plannen

Attendees

Maarten-Jan van Gool (Logica/RU), Jeroen Visser (Logica), Ruud Bakker (Amsterdam Airlines), VZV (Vereniging van Zeecontainer Vervoerders).

Author of this piece

Jeroen Visser

Date

The 11th of October, 2011.

A.3.1 Report

We waren onderdeel van de jaarvergadering van de VZV (Vereniging van Zeecontainer Vervoerders). Het geheel begon met ontvangst met diner/buffet. Daar als verschillende personen gesproken, onder andere Paul Swaag van Portbase. Hier en daar al 'getoetst' hoe mensen over onze 'ideeen' (lees: agents, verschuiving van klantvraag) denken.

Vervolgens naar de vergader kamer met zo'n 50 a 60 man, waar eerst de jaarvergadering werd gehouden.

Daarna eerst presentatie van Ruud Bakker (ex-collega van Amsterdam Airlines) over slots in de luchtvaart. Daarnaast ik met een presentatie over SPITS en een vergelijk tussen luchtvaart en wegvervoer (met als conclusie: beide zijn precies hetzelfde). In mijn laatste sheet geeft ik een 'teaser' waarmee de discussie gestart kan worden, aangevoerd door Paul Swaag.

De discussie kwam, in mijn ogen, wat moeilijk op gang. Het eerste half uur ging voornamelijk over slots zoals in de luchtvaart. Veel ja's en nee's. Algemene conclusie was dat voor het wegvervoer slots bij de terminal niet echt zou werken. Het grootste probleem was dat je met de klant zit: die geeft een eindtijd op, ofwel die is bepalend. Wil de terminal dan ook een slot uitgeven, zou dit dan eigenlijk moeten in overleg met de klant (lees: eigenaar/bestemming van de container). Dit zal vrij zeker niet gebeuren, dus slots zoals in de luchtvaart zal het niet echt worden. Dat er iets moet gebeuren met slots is wel nodig. Dus de eindconclusie is nog wel open: aan een kant geen (luchtvaart)slots, maar er moet wel een regulering c.q. iets slot-achtigs komen, want de huidige situatie is niet bepaald optimaal.

Een interessant deel was het volgende. Iemand noemde: waarom doen we geen gedifferentieerde prijsstelling: wil je tijdens de piek een container hebben, kost je dat als klant 100 EUR meer, omdat we als maatschappij verlies hebben. Meteen consternatie in de zaal... 'maar als ik dat doe, en mijn concullega doet het wel voor het lage tarief, dan ben ik mijn werk kwijt'. En toen kwam een mooi stukje commentaar: oh, dus we zijn hier als een vereniging. Maar zodra we de deur uit zijn concureren we elkaar gewoon weer kapot...

Een andere mooie discussie was het dynamisch plannen. Ik gaf aan dat 'alles kan': ze kunnen real-time alles zien. Van verwachtte vertraging op de weg, tot verwachtte vertrektijd op de terminal, en dat alles real-time dus. Mijn voorbeeld: het is nu druk op de terminal, dus, gezien vanuit dynamisch plannen, 'ga maar linksaf en wat anders doen'. Weer consternatie in de zaal: "Alsof ik zomaar wat anders kan gaan doen". En daar zit ook meteen de crux. De huidige werkwijze is een mix van statisch plannen en reactief bijsturen. Ofwel, er word een dagplanning gemaakt, en pas als we "bericht krijgen van de chauffeur dat er echt iets vreemds aan de hand is", dan pas gaan we bijsturen. Dus geen pro-actieve dynamische planning. Belangrijkste reden (zoals ik die daar heb opgevangen): de klant. De klant wil gewoon zijn container om 14:00, dus die heb ik maar te halen. Ze zeggen dit wel, maar tegelijkertijd hebben ze eigenlijk nooit contact met de klant gehad hierover. Ze zien het als een gegeven, welke niet bespreekbaar is met de klant. Daarbij zit het niet in de genen (ref. De consternatie die onstond als je een echt dyn. plan voorbeeld geeft) om je programma 'zomaar' om te gooien.

Wat mij betreft ligt in het laatste dan ook de grootste uitdagingen:

- kunnen we het voor elkaar krijgen om klant en vervoerder aan elkaar te koppelen (in ieder geval met elkaar te laten praten)
- kunnen we zorgen voor een cultuuromslag bij de vervoerders van statisch reactief plannen naar dynamisch proactief plannen? Technisch kunnen we het, maar de vraag is dus cultureel.

A.4 Summary transport company meetings

Wednesday the 21st of December Hans Moonen and myself visited three transport companies. The first goal was to get a general overview of the problems within container transport as viewed from the transport companies. The second goal was to put our own ideas to the test, and see what the transport companies think of them.

A.4.1 Hebra Containervervoer

Company:	Hebra Containervervoer.
Interviewers:	Maarten-Jan van Gool and Hans Moonen
Interviewee:	Johan Groenevelt
Date:	21st of December 2011. 10:30.

General company information

- 50 trucks active in container transport
- ±50% reefers [different process: shorter distance; always one-way empty; time critical (especially import), due to higher charges for reefer rental.
- Most of transport takes place in the Benelux: ±80% in the Netherlands.
- Hebra focuses on longer trips (for the non-reefers).
- 4 planners plan the trips by hand: one by one.

Johan Groenevelts opinion

1. Main problems in container transport at the moment:
    - The lack of accurate information (from the terminal).
    - The lack of interest of the terminal regarding waiting times outside of the terminal: the terminal only cares what happens on the terminal.
2. Waiting profile:
    - Waiting profiles exist at the moment in the head of the planners.
    - Waiting profiles tend to be rather predictable if you know the day (in the week, but also day in the year) and the particular terminal.
    - Sharing arrival times already takes place, however this information is not always correct.
    - Assuming the information in the waiting profile is reliable, the planners will probably have some use for it.

3. Container switching:
    - Hard to say, probably difficult and very situation dependent.
    - Dependent on truck and container.
    - No switching between different companies.
4. Customer influence:
    - The terminal should be more forthcoming with information regarding delays: informing the customer on delays is important, but sometimes difficult for this reason.
    - Depending on the customer, customer demands regarding the delivery time can be flexible.
5. General remarks:
    - Is one of the participants of "Truckload Match": a cooperation between companies to decrease empty miles. This system only works in a very limited amount of cases. The matching is very strict: i.e. timeframes for pickup/delivery & container provider. As a result there is a low percentage of matches.

My thoughts

- Johan Groenevelt is very skeptical of new developments. Johan does not really believe in new technology, nor that the transport sector can be changed in significant ways.
- Nevertheless, he believes that certain changes will help improve the container transport, and his company takes part in new(er) initiatives like Truckload Match, and a research project driven by Deal Services.
- It seemed to me that he really wanted to say that no improvement is possible, but that "reality forces him to say that some improvement is possible.

A.4.2 Van der Most Transport B.V.

Company:	Van der Most Transport B.V.
Interviewers:	Maarten-Jan van Gool and Hans Moonen
Interviewee:	Paul Dijkshoorn
Date:	21st of December 2011. 13:00.

General company information

- 80 trucks active in container transport
- Less than 10
- Most orders within the Benelux.
- Focuses on the longer trips.
- Utilizes LZVs (lange zware vrachtwagens), which are able to combine 1 20FT + 1 40FT (or 3 20FT) containers.
- Has its own depot and cranes to temporarily store and switch containers. Is used mostly to decrease empty miles: when a truck delivers a container at a terminal, it also picks up one (or two). If this container has to be delivered the next day, or for example 2 20ft containers are picked up that have to be delivered in totally different parts of the country, the depot can be used to switch containers and therefore decrease empty miles and miles in general.
- Takes part in Truckload match. Of 160 transports a day, it will make approximately 2 matches a day.

Paul Dijkshoorn opinion

1. Main problems in container transport at the moment:
    - Unpredictability of events:
        - Weather.
        - Technical issues (especially at the terminal: cranes that break down).
        - Business at the terminal.
        - Traffic.
    - Serious lack of communication (from the terminal).
2. Waiting profile:
    - The terminal communicates badly.
    - Trucks delivering containers are already moving: even if the time constraints are not really there, there is no use for sending the truck to a parking lot. And without time constraints it is only viable to pick up a container when another is delivered.
3. Container switching:

  - It is not busy enough at the terminal at this moment for this to be effective.
  - Really time dependent: customers want their container on time.
  - Would only work for 40ft containers.
  - The terminal could and should consider the method of container placement in stacks.

4. Customer influence:
  - The customers will is law: they give a place and time, and thats it.
  - It is the problem of the transport company that there are delays, the customer does not care for the details, or who to blame.
  - The customer will not pay for terminal-caused delays.

5. General remarks:
  - The transport sector is really a cutthroat business. Margins on transport are very low (2%).
  - Transport companies cannot make a stand to the customer because the customer can easily switch to a competitor.
  - The customer doesnt really care about the details, he just wants his container on time: if its too late, the transport company is to blame.

My thoughts

- Although Paul Dijkshoorn was not that positive regarding waiting profiles, I think waiting profiles would solve most of the terminal communication issues. Technical difficulties would show in the waiting profile as well.
- Although Paul seemed to be very conservative, at least some progress and innovation is attempted: the company invested heavily in cranes and land to create a buffer for transport to optimize it (the only transport company which has this in place). Even though the yield is very low, they take part in the truckload match system. It seems to me this company definitely is interested in new developments.
- It isnt going very well with Van der Most. While the other two companies said it to be very busy, at van der Most they told us business is slow. This might be due to the nature of the business with little reefers. Nevertheless, hard economic times may also have resulted in a less positive attitude towards possible innovations.

A.4.3 Post Kogeko

Company:	Post-Kogeko
Interviewers:	Maarten-Jan van Gool and Hans Moonen
Interviewee:	Ben van Zeijl
Date:	21st of December 2011. 15:00.

General company information

- 35 trucks on containers and 16 trucks on inter-terminal transport. (and another 400 trucks in other operations)
- Working in the Cool barge project: A collaborative with barges, different customers and transport companies to use intermodal transport. Reefers sail between the Waalhaven and the Maasvlakte, in order to avoid congestion on the a15.
  - Post-Kogeko supports this new initiative, although they dont expect to get a positive return on investment.

Ben van Zeijls opinion

1. Main problems in container transport at the moment:
    - The terminal says: all transport companies arrive at the same moment. The transport companies say: the terminal does not respond to peek situations.
    - Waiting in front of the terminal is considered by the transport companies as a problem for the terminal, while the terminal only considers the waiting time on the terminal.
2. Waiting profile:
    - Not really helpful for Post-Kogeko: Post-kogeko is mostly in the business of transporting large amounts of containers from and to one terminal. A starting time is agreed on, and then the assigned trucks will continuously drive between the customer and terminal until the job is done. Ben thinks this will be useful for for example van der Most, because they have their own depot.
    - This is due to the primary focus from Post-Kogeko on reefer containers, which tend to arrive at the same terminal by the same ship. All customers have containers aboard the same ship(s). 3) Container switching:
    - This could work at Euromax and ECT home. The case of ECT Home was discussed in more detail: containers tend to be placed in the same

stack: it is not unthinkable that queues of multiple hours occur at a terminal because 35+ trucks are queuing for the same stack (all hunting to be the first to deliver a reefer to a customer).

- However, the correct information is required.

3. Customer influence:

    - Regarding customer influence a new idea has been added: keeping the customer up-to-date can greatly increase efficiency. When the customer knows which truck is going to arrive for what and when, the customer can make preparations.
    - Customers will be happy to be involved in programs like the Cool barge project: when the transport becomes cheaper.

My thoughts

- Post-Kogeko clearly has the most positive view on innovations in transport, and is also openly willing to try new stuff, even when they very well may lose money on it (Cool barge for example).

A.4.4 Conclusion

The main problems according to the transport companies are:

- The lack of transparency and communication from the terminal.
- The (so it seems) endless debate regarding whose problem the waiting time in front of the terminal is.
- A general lack of information sharing, which results in difficulties when responding to unexpected events.
- Because of the heavy competition between transport companies, the transport companies together cannot make a stand to the customers or terminals.

The overall conclusion is that information sharing can improve decision making. However, the suggestions we did will only apply in (very) specific circumstances. It is difficult to predict how many times this information would be helpful, and it also can vary between different transport companies. This is because transport companies have little “wiggle room”, because of customer demands are strict, profits per transport are low and terminals are static and only concerned with the business on the terminal.

However, as the truckload match system shows, even when the yield is very low, a small yield is still useful for transport companies. And no transport company thinks a larger yield is achievable anyway in the planning regard. It is one big prisoners dilemma, in which everyone gets stuck in the least optimal situation.

Only one part of transport seems to be beneficial for optimization for all parties: the transport time on the terminal. Optimizing the placements of containers in stacks, and optimizing the spreading of trucks over the different stacks should be beneficial for the customer, terminal and transport company. Perhaps the focus should lay here.

A.5 Port reports

Several papers report on the situation in the port. Each of these papers reports on several issues related to transport. In table 18 the issues mentioned are listed, together with in which paper the point is mentioned. It should be noted that Kolkman 2009 relates to barges, while the other reports consider container transport.

Issue:	Mentioned in:			
	Connekt 2003	van den Broek et al. 2010	Horst et al. 2008	Kolkman 2009
Waiting Lines at the counter	$\surd$			
Inspections are inefficient	$\surd$			
Automated stacking cranes are not used optimally	$\surd$			
Not everyone speaks “the same language”	$\surd$			
Sharing information is not beneficial for everyone	$\surd$			
Lack of sharing (correct) information	$\surd$	$\surd$	$\surd$	$\surd$
Peak hours	$\surd$		$\surd$	
Lack of support for peak rates.	$\surd$			
Lack of coordination	$\surd$	$\surd$	$\surd$	$\surd$
Inefficiencies in the different modalities		$\surd$		
Too few international promotion of the Netherlands		$\surd$		
Too few investments in infrastructure		$\surd$	$\surd$	
A lot of terminal visits per ship				$\surd$

Table 18: Different port reports and the issues mentioned.

Appendix B

Simulation

In this appendix the implementation process of the simulation will be described in more detail. In section B.1, we will describe the design steps of the Gaia methodology in relation to our agent design. In section B.2 the different behaviors of the various agents will be discussed. Section 5.5.3 will discuss the methodology of gathering route information. In the last section, section B.3, the elementary reports of the ANOVA's in our research can be found.

B.1 Agent design

In this part of the appendix the agent design for our multi-agent system is described, using the Gaia methodology M. Wooldridge et al. (2000).

There are five roles in the system: the terminal-role, the transport-role, the transport company role, the customer-role and the transport time estimation role. The role schemas can be found below.

B.1.1 Role schemes

Role Schema: waiting-profile-role
Description: This role ensures that the waiting profile is up-to-date, and informs the other agents when requested.
Protocols and Activities: InformRequester, update waiting profile
Permissions: reads supplied *Arrival Information* changes waiting profile
Responsibilities: Liveness: • waiting-profile processing = (update waiting profile. InformRequester)$^{\omega}$

Role Schema: transport-role
Description: This role ensures that the transport of a container is carried out as efficiently as possible.
Protocols and Activities: transport containers, update terminal, apply container switch
Permissions: read supplied *trip information* read supplied *company container list*
Responsibilities: Liveness: • transport-role = (transport containers. update terminal)$^{\omega}$ + apply container switch Safety: • containers arrive on time.

Role Schema: transport company-role
Description: This role ensures orders (trip information) get assigned to trucks.
Protocols and Activities: request transport information, select transport information, assign truck, inform truck
Permissions: read supplied *terminal waiting profile* read supplied *trip information*
Responsibilities: Liveness: • transport company-role = (request transport information. select transport information. assign truck. inform truck)$^{\omega}$ Safety: • containers arrive on time. • expected transport time should be as low as possible.

Role Schema: transport time estimation role
Description: This role ensures accurate transport time estimations are given to anyone who requests these.
Protocols and Activities: estimate transport time, inform requester on transport time
Permissions: reads supplied *travel durations* reads supplied *trip information* modifies trip information
Responsibilities: Liveness: • transport time estimation role = (estimate transport time. inform requester on transport time)*

Role Schema: customer role
Description: This role ensures orders are placed with transport companies.
Protocols and Activities: place order
Permissions: generates trip information
Responsibilities: Liveness: • customer role = place order$^{\omega}$

B.1.2 The agent model

terminal-role	→	Terminal Agent
	→	Stack Agent
transport-role	→	Truck Agent
transport company role	→	Transport Company Agent
customer-role	→	Customer Agent
transport time estimation role	→	Transport Time Estimation Agent

Because the terminal role is divided between stack and terminal, it is more convenient to have these as separate agents. The stack agents would serve in a supporting role to the terminal.

B.1.3 The aquantance model

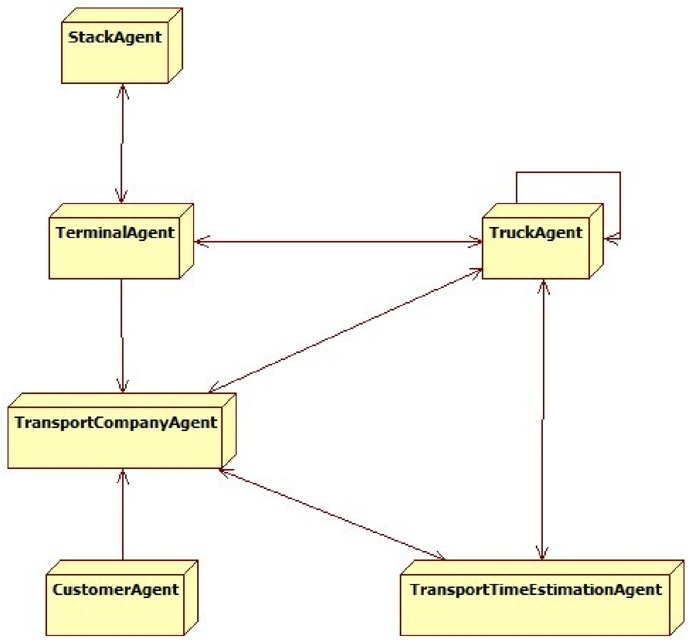


Figure 20: The agent model.

B.2 The behaviors in the agent system

In this section we will discuss the objects we built in our program, using several diagrams. Per agents all of the behaviors will be discussed. We will also discuss the objects the agents used to communicate with each other. Note that standard within JADE is to use British English.

B.2.1 Truck agent

HandleOrderBehaviour

The main behavior for a truck. This behavior is started up as soon as a truck gets an order assigned. The behavior is responsible for requesting updates on the ETA at the transport time estimation agent, and updating the terminal on this ETA.

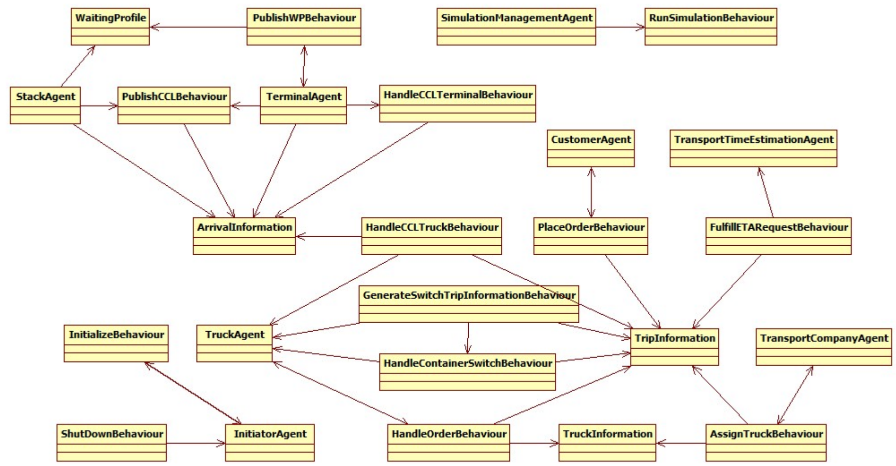


Figure 21: The UML diagram (logical view). All the objects in the simulation and their relation are displayed.

HandleCCLTruckBehaviour

This behavior is responsible for requesting the list of containers at the terminals that belong to the trucks company (the Company Container List: CCL). This list is subsequently used in "GenerateSwitchTripInformationBehaviour" to find a suitable truck for a container switch (only used when container switching is enabled).

GenerateSwitchTripInformationBehaviour

This behaviour walks through the whole CCL. If one of these containers has a shorter stack waiting time, the complete trip information is requested from the belonging truck. This information is passed on through to the "HandleContainerSwitchBehaviour" (only used when container switching is enabled).

HandleContainerSwitchBehaviour

The Handle container switch behavior compares the current situation to the possible new situation after the switch. If the total trip time (of the two trips) is shorter in the new situation, this behavior initiates the container switch (only used when container switching is enabled).

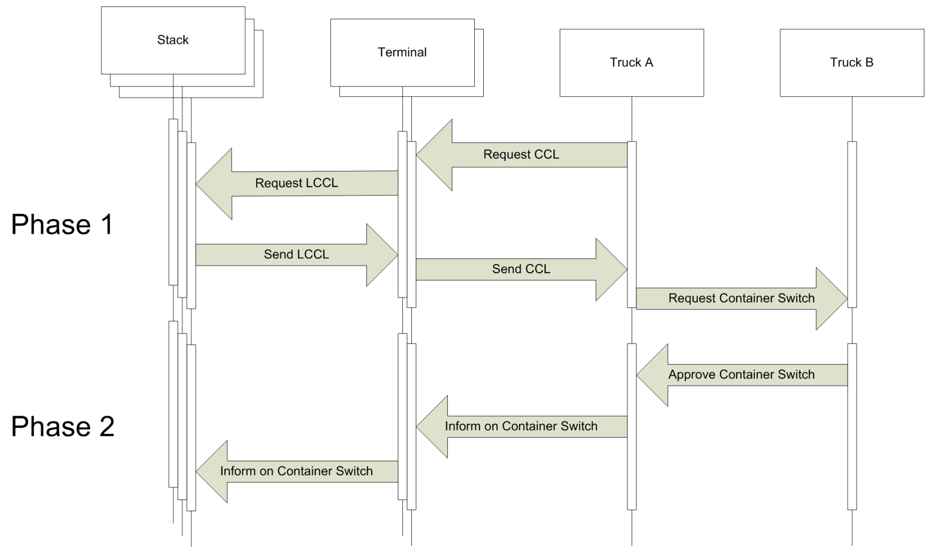


Figure 22: The container switch sequence diagram. Displays the sequence of communications between the different agents.

B.2.2 Transport company agent

AssignTruckBehaviour

This behavior matches orders to trucks. Orders with the closest "desired arrival time" are handled first. Besides truck assignment, this behavior is also responsible for selecting a suitable departure time. If "make use of waiting profiles" is enabled, the best possible departure time, given the customer demands, will be selected. When disabled, the truck will leave instantly.

B.2.3 Terminal agent

PublishWPBehaviour

The trucks communicate their expected arrival time at the terminal to the terminal. The terminal in turn, will use this behavior to publish the waiting profile.

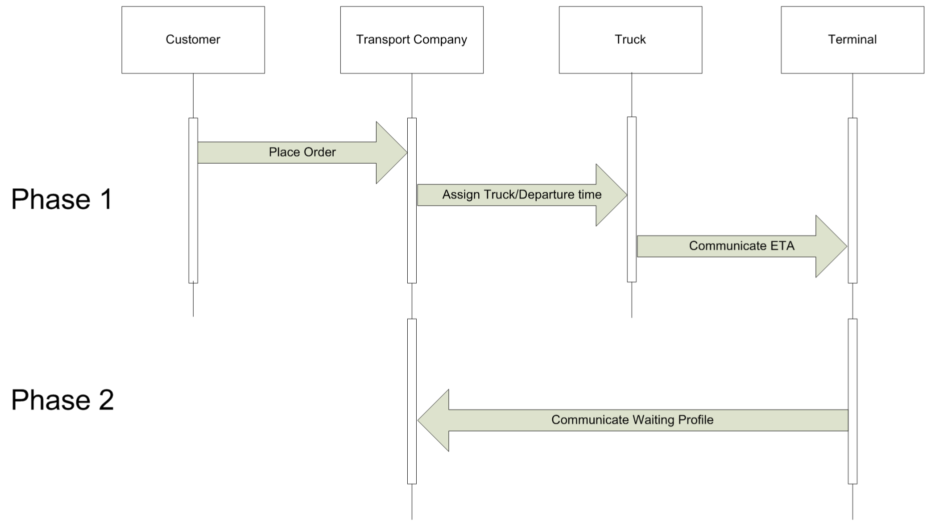


Figure 23: The place order sequence diagram. Displays the sequence of communications between the different agents.

HandleCCLTerminalBehaviour

When a truck requests the terminal for the CCL, the terminal will pass this request on to the different stacks. The stacks will reply with their local CCL. This behavior compiles these into one big CCL, before passing this through to the requester.

PublishCCLBehaviour

This simple behavior publishes the CCL for the terminal.

B.2.4 Stack agent

PublishCCLBehaviour

This simple behavior publishes the CCL for the stack.

B.2.5 Customer agent

PlaceOrderBehaviour

This behavior generates orders for a customer. It will generate a trip information object, with all the necessary information an order needs.

B.2.6 Transport time estimation agent

FulFillETARequestBehaviour

This behavior fulfills a request on an update on the ETA's on the different locations.

B.2.7 Initiator agent

InitializeBehaviour

This behavior starts up all the agents for the simulation, and will set the variables.

ShutDownBehaviour

This behavior will shut down all the agents when the time is up, or when all the orders are processed.

B.2.8 Simulation management agent

RunSimulationBehaviour

This behavior will restart the initiator agent when all the agents are shut down.

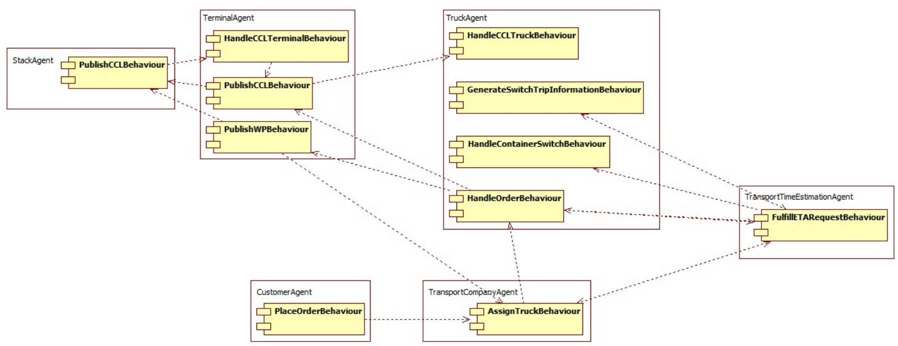


Figure 24: The process view. Here each of the agents and their behaviors are displayed, and the communication lines between different agents and behaviors.

B.3 Elementary reports

In order to analyze the data we gathered from the simulations, we used several statistical tests. In this appendix the elementary reports of these tests can be found Ellis (2006a,b). we analyzed the data using the program PASW Statistics SPSS (2009).

B.3.1 Trip times

We performed a 2-factor between subject ANOVA to investigate the effect of waiting profiles and Container switching on trip times. In this section the elementary report of this ANOVA can be found.

Design:

Dependent variable:	=	Trip time (quantitative, 1 measurement per trip).
Independent variables:		
Between-subject factor A	=	Making use of waiting profiles (yes/no)
Between-subject factor B	=	Making use of container switching (yes/no)

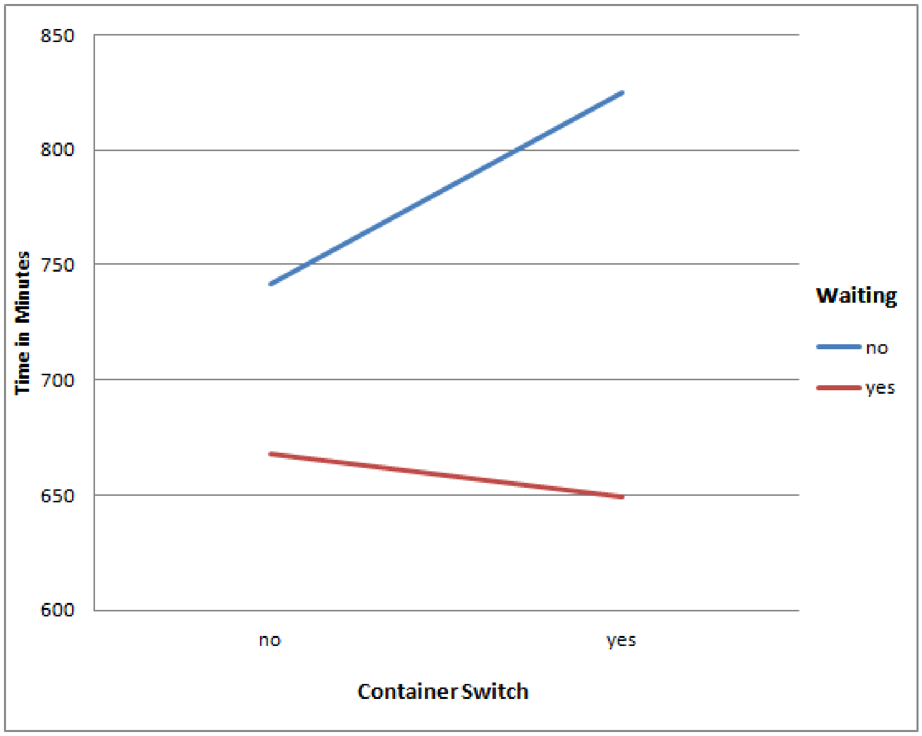
Degree of control:

Both factors are experimental.

Aggregated data:

	WP(no)	WP(yes)	
CS(no)	μ = 741.42	μ = 667.80	μ = 706.24
	σ = 181.39	σ = 186.67	
	n = 1783	n = 1632	
CS(yes)	μ = 824.92	μ = 649.07	μ = 745.62
	σ = 382.43	σ = 159.18	
	n = 1406	n = 1155	
	μ = 778.24	μ = 660.04	μ = 723.11

Interaction plot:



Hypotheses:

H_0(WP): $\mu_{WP(no)} = \mu_{WP(yes)}$
H_a(WP): H_0(WP) is false
H_0(CS): $\mu_{CS(no)} = \mu_{CS(yes)}$
H_a(CS): H_0(CS) is false

H_0(WP×CS):

$$\begin{aligned}
\mu_{WP(no)\&CS(no)} &= \mu_{WP(no)} + \mu_{CS(no)} - \mu_{total} \quad \text{and} \\
\mu_{WP(no)\&CS(yes)} &= \mu_{WP(no)} + \mu_{CS(yes)} - \mu_{total} \quad \text{and} \\
\mu_{WP(yes)\&CS(no)} &= \mu_{WP(yes)} + \mu_{CS(no)} - \mu_{total} \quad \text{and} \\
\mu_{WP(yes)\&CS(yes)} &= \mu_{WP(yes)} + \mu_{CS(yes)} - \mu_{total}
\end{aligned}$$

H_a(WP×CS): H_0(WP×CS) is false

ANOVA-table:

Source		df	SS	MS	F	p	eta^2
Between		3	26496877.83	8832292.61			
	CS	1	1525551.51	1525551.51	25.97	.000	.004
	WP	1	22626678.87	22626678.87	385.16	.000	.061
Interaction CS×WP		1	3799412.75	3799412.75	64.67	.000	.011
Error		5972	350836887.23	58746.97			
Total		5975	377333765.07				

Decisions:

1. The p-value for container switch is significant ($p < .05$), so H_0 is rejected. The waiting times in the population differ between performing the container switch and not performing the container switch. This effect is weak ($eta^2 = .004$).
2. The p-value for waiting profile is significant ($p < .05$), so H_0 is rejected. The waiting times in the population differ between using waiting profiles and not using waiting profiles. This effect is weak ($eta^2 = .061$).
3. The interaction is significant ($p < .05$), so H_0 is rejected. There is interaction between the factors Container switch and waiting profiles.

Causal interpretation:

See section 5.8.

B.3.2 Amount of trips per day

Design:

Dependent variable:	=	Amount of trips per day (quantitative, 1 measurement per trip).
Independent variables:		
Between-subject factor A	=	Making use of waiting profiles (yes/no)
Between-subject factor B	=	Making use of container switching (yes/no)

Degree of control:

Both factors are experimental.

Aggregated data:

	WP(no)	WP(yes)	
CS(no)	μ = 118.87	μ = 96.00	μ = 106.72
	σ = 14.09	σ = 16.36	
	n = 15	n = 17	
CS(yes)	μ = 108.15	μ = 96.25	μ = 102.44
	σ = 17.24	σ = 10.58	
	n = 13	n = 12	
	μ = 113.89	μ = 96.10	μ = 104.84

Hypotheses:

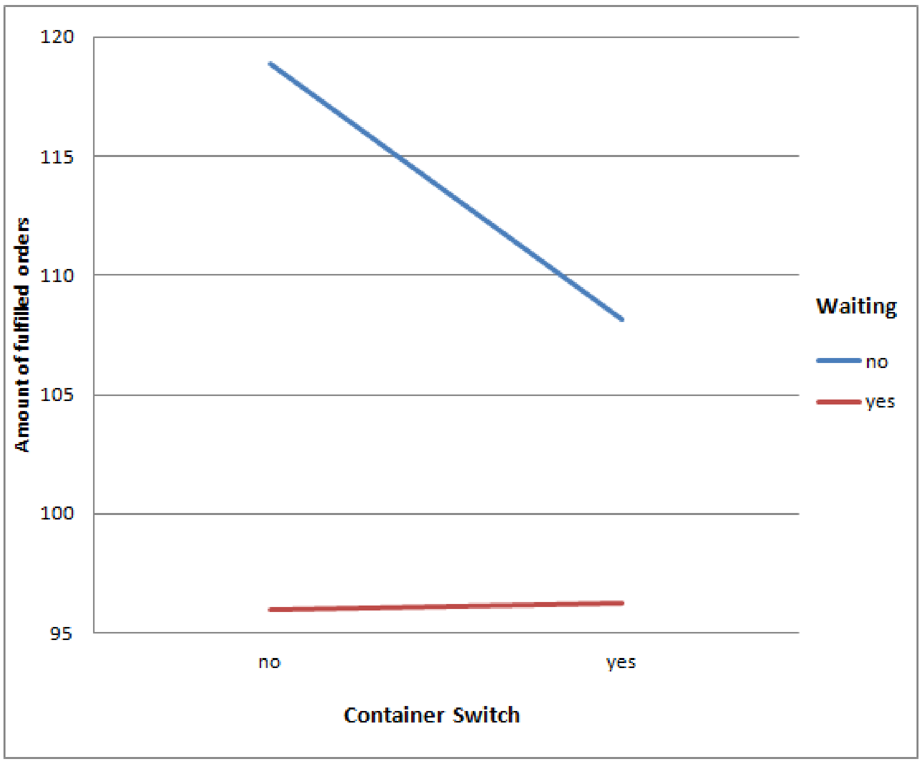
H_0(WP): $\mu_{WP(no)} = \mu_{WP(yes)}$
H_a(WP): H_0(WP) is false
H_0(CS): $\mu_{CS(no)} = \mu_{CS(yes)}$
H_a(CS): H_0(CS) is false

H_0(WP×CS):

$$\begin{aligned}
\mu_{WP(no)\&CS(no)} &= \mu_{WP(no)} + \mu_{CS(no)} - \mu_{total} \quad \text{and} \\
\mu_{WP(no)\&CS(yes)} &= \mu_{WP(no)} + \mu_{CS(yes)} - \mu_{total} \quad \text{and} \\
\mu_{WP(yes)\&CS(no)} &= \mu_{WP(yes)} + \mu_{CS(no)} - \mu_{total} \quad \text{and} \\
\mu_{WP(yes)\&CS(yes)} &= \mu_{WP(yes)} + \mu_{CS(yes)} - \mu_{total}
\end{aligned}$$

H_a(WP×CS): H_0(WP×CS) is false

Interaction plot:



ANOVA table:

Source		df	SS	MS	F	p	eta^2
Between		3	5307.90	1769.30			
	CS	1	383.10	383.10	1.71	.196	.031
	WP	1	4230.98	4230.98	18.91	.000	.263
Interaction CS×WP		1	420.59	420.59	1.88	.176	.034
Error		53	11859.68	223.77			
Total		56	17167.58				

Decisions:

1. The p-value for container switch is not significant ($p > .05$), so H_0 is kept. The amount of orders in the population (of days) do not differ between performing the container switch and not performing the container switch.

2. The p-value for waiting profile is significant ($p < .05$), so H_0 is rejected. The amount of orders in the population (of days) differ between using waiting profiles and not using waiting profiles. This effect is strong ($eta^2 = .263$).
3. The interaction is not significant ($p > .05$), so H_0 is kept. There is no interaction between the factors Container switch and waiting profiles.

Causal interpretation:

See section 5.8.