Delft University of Technology

Strategies to Regulate Inbound Logistics at Convention Centers

A Case Study of the RAI Amsterdam

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Preface

This thesis is the result of my graduate internship at the RAI Amsterdam, which is the final step in completing my Master in Transport, Infrastructure and Logistics at the Delft University of Technology. During this internship I was able to discover all facets of convention centers and their logistics. The goal of my internship was to design a new logistics system and discover the effects of it. The proposed designs had to comply with RAI requirements. Based on my research I was able to give recommendations to the RAI, some of which seem promising and fit for future implementation.

My internship at the RAI has been a very good experience. I would like to thank those with whom I have worked together. The RAI has always made me feel welcome and included me within their team. I would especially like to thank the entire traffic department team. They were always willing to answer my questions and help me when needed. I would also like to thank Wim Braakman and Paul Swaak for their useful insights and knowledge of the RAI, which were invaluable to my research.

Besides thanking the RAI, I would also like to thank my TU Delft graduation committee: Dr. J.M. Vleugel, Dr. F.Schulte and Prof. Dr. R.R. Negenborn . With the help of their feedback and due to their critical questions I was challenged to think further than my initial ideas. Moreover, I would like to express my gratitude to my family, colleagues and friends for their support and understanding during this research, but also throughout my entire studies. Without them it would have been much harder.

Iris Vendrik

Summary

Convention centers are often located within urban areas. These urban areas are becoming more crowded every year, which results in challenges for convention centers. These challenges are lack of space and governmental regulations. Convention centers sell space and in order to increase income more commercial space needs to be established. Since space is limited convention centers can not expand and therefore rearranging the current space is necessary. Much space around convention centers is used for logistics. Organising conventions requires many truck movements, which can amount to hundreds on a daily basis. Handling all these trucks and trailers requires a lot of space. If logistic space is limited this could influence the performance of the logistics system and queues and long waiting times can emerge. The literature on convention centers and their logistics is limited. Therefore, it is unclear how convention centers could improve their logistic performance this. This research aims to address this research gap.

In order to study logistics at convention centers a case is used. The case of the RAI Amsterdam is used which is the largest convention center in the Netherlands. The RAI is dealing with the challenges mentioned above: it is located within the city center of Amsterdam and the municipality will introduce new regulations is the near future. These regulations include an environmental zone and a reduction of nuisance on the north side of their complex. To comply with these regulations the RAI is looking into options to close their logistic space on the north side completely and shift all logistic activities to the south side. Closing off the north side will decrease capacity with 70%. At the south side space is limited and it will not be possible to create as much logistic space as they now have on the north side. A reduction in space could have negative effects on the performance. In order to address these issues the following research question will be answered within this research: *How can the RAI redesign the freight logistics system to reduce negative external effects, improve logistic performance and maintain commercial space?*

To structure the design process the DMADV method is used. This method consists of the following 5 phases: define, measure, analyse, design and verify. Within the define phase literature on convention centers and several other industries is studied. Within the literature study several technologies and strategies were found that could be interesting for convention center logistics. These strategies and technologies are: truck appointment systems, automated vehicles, conveyors, cross-docking, underground logistics and IT systems. In the measure phase the current logistics system of the RAI is described. Several factor on which improvements could be made came up such as: communication between RAI departments, communication between external parties and RAI, a time consuming unloading method and too much nuisance caused by trucks and trailers at the north side. The analyse phase examines the obtained and collected data of the RAI. Analysis of the data showed that maximum unloading times were often exceeded, that there were long waiting times and that 60% of all trucks and trailers unload at the north side. The current situation will be modelled with the use of a Discrete Event Simulation (DES) model. With the obtained data this DES model can be verified and validated. After the analysis a requirement analysis is performed and several designs are introduced. These designs are then simulated with the use of a discrete event simulation model to see the effects on performance, space and negative external effects. The verified and validated DES model of the current situation will be adjusted to the designs. Finally an analytical hierarchy process is performed to see which design is most desirable for the RAI. The performance of the logistics system is measured by the space, unloading time, waiting time, delivery time, number of vehicles (forklifts ad EPTs), nuisance, costs and flexibility.

In total five different designs are included. The proposed designs have certain similarities, namely they all include the following three strategies: truck appointment system, extending operational time and cross-docking. In the simulation model of the current situation these strategies showed that they can decrease unloading times with 50% and decrease waiting times as well. The designs differ in infrastructure and material handling equipment. Within design 1 a new logistic center is created on the south side. Trucks and trailers that have goods for the north side unload at the south side. The goods are then transported through a tunnel to the north side with the use of EPTs. In design 2 the new logistic center is created underneath the north side. Trucks and trailers that arrive drive to the south side an drive through a tunnel here to enter the north side. The goods are unloaded underground and transported with EPTs to the halls. Designs 3, 4 and 5 follow the same approach as design 1. However, they use different transportation modes within the tunnel. After the tunnel the goods are further transported to the halls with EPTs. Design 3 uses conveyor belts, design 4 uses rail guided vehicles and design 5 uses automated guided vehicles. To test the designs different scenarios have been run. These scenarios differ in the operational time and the amount of arriving trucks and trailers. Every scenario has been run 25 times for a simulation duration of almost one day (21 hours).

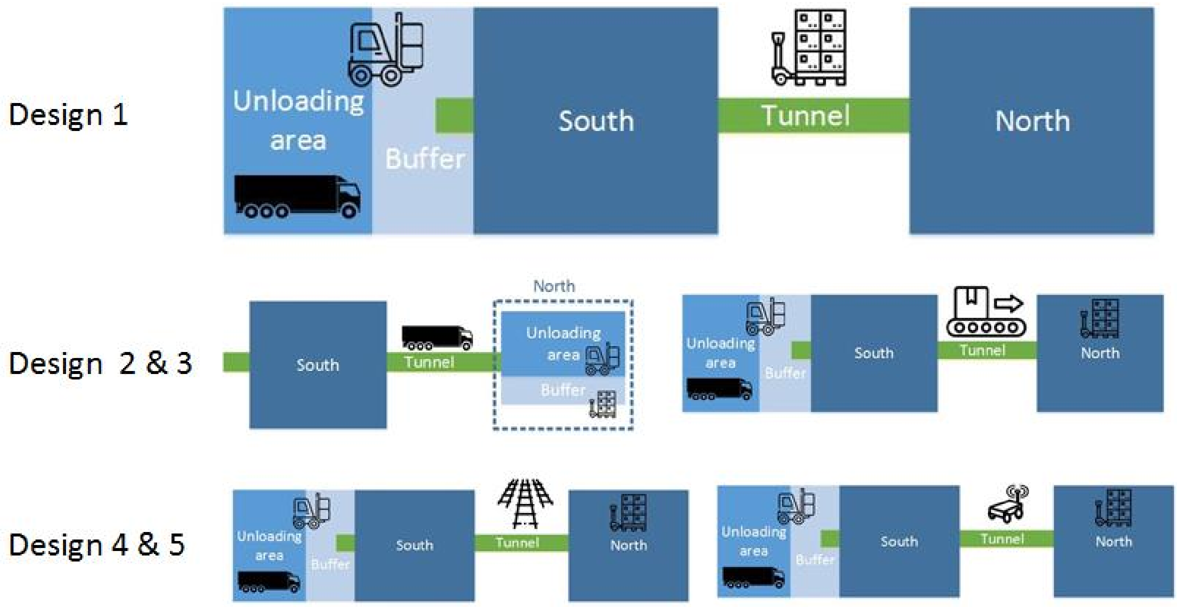


Figure 2: Overview of the five designs

The outcomes of the simulation results are used as the inputs of the Analytical Hierarchy Process (AHP). Three employees of the RAI were asked to assign weights to the decision criteria. Based on their individual weights the combined weights of the criteria could be determined. The outputs of the simulation model were normalized and multiplied by these weights. The outcomes of the AHP showed that the differences between the designs are small. There is not one design that can be defined as the best choice. However, the AHP gave some useful insights. Overall, the outcomes showed that design 3 is the least preferable option since it scored lowest on all scenarios. Design 2 scored precariously and has long waiting times whereas design 1 scored best of all designs. Design 4 and 5 performed well, especially on busier days with long operational times. The advantages of design 4 and 5 are that they reduce buffer space compared to design 1. Design 1 has a high flexibility and probably the lowest costs; however, it needs much buffer space.

Based on this research a conclusion can be drawn on how convention centers can improve their performance while reducing negative external effects and maintaining or increasing commercial space. The logistics at convention center should be better controlled. This can be done by implementing a truck appointment system. During busy days operational time should be extended in order to avoid waiting times and queues. The unloading process can be sped up with the introduction of cross-docking. When working with a cross-dock buffer space is needed to store pallets. Depending on the design of the infrastructure and the material handling equipment the required space for these buffers differ. All proposed designs reduce the nuisance and maintain the same amount of commercial space. Designs which include automated vehicles reduce the required buffer space; however, they reduce the flexibility. The designs are based on the infrastructure of the RAI and, therefore, other designs might lead to a better performance at other convention centers.

This research led to several recommendations for the RAI. Implementing one of the designs will not be possible within a short period of time. However, the RAI can already start improving their current logistics by implementing a truck appointment system. By doing this waiting times can be reduced and there is more control of logistic process. On busy days operational times should be extended to ensure that the arriving trucks and trailers remain within the capacity. The RAI should also start a cross-docking trial to see how this performs in the real world and to find out if it reduces unloading times as much as is expected. Out of the five designs, design 1 seems most desirable for implementation. The RAI should research how much space they have available for buffers on the south side to see if there is enough space available for the required buffer space. The advantage of design 1 is that it can easily be adjusted by implementing automated vehicles. if the RAI desires this. Finally the RAI should only close off the north side if the new logistics system showed in practice that it is able to handle the arriving trucks and trailers and their goods.

Contents

List of Tables

List of Figures

List of Abbreviations

AHP	Analytical Hierarchy Process
DES	Discrete Event Simulation
DRIPS	Dynamical Route Information Panels
DMADV	Define Measure Analyse Design Verify
DMAIC	Define Measure Analyse Improve Control
EPT	Electric Pallet Truck
FIFO	First In First Out
KPI	Key Performance Indicator
LGV	Laser Guided Vehicle
LIFO	Last In First Out
LP	Logistic Partner
MCDA	Multi Criteria Decision Analysis
NLN	New Logistic North
RA	Requirement Analysis
RE	Requirement Engineering
RFID	Radio Frequency Information
RGV	Rail Guided Vehicle
SL	Self Loader
ULS	Underground Logistics System

Part I

Define

1 | Introduction

In this chapter the performed research is introduced. First the context is described and the case of the RAI Amsterdam is introduced. After this, the research problem, research scope, research objective and the research questions are introduced. Finally the research approach and the used methodologies will be discussed.

1.1 Convention Centers

Convention centers are large buildings designed to host conventions and attract visitors, exhibitors and organisers. Most convention centers are located within urban areas since these locations offer several positive characteristics such as good connections to airports, public transport, highways and they also offer several side activities for visitors and exhibitors. These characteristics attract more visitors, exhibitors and organisers increasing the profit of the convention center, therefore a good location is of high importance for a convention center (ExhibitCity, 2014).

Organising a convention requires a large number of logistic operations. A convention consists of hundreds of stands which all need to be built and filled with furniture and other goods. All these materials and goods need to be delivered to the convention center and should be brought to the right place within the halls. In order to do this, hundreds of truck movements are required. The logistics at convention centers are highly complex due to the variety of goods that are delivered, the time-span and the different activities such as loading, unloading, storing and transporting (S. X. Zhang, 2012b). The logistics can be divided into three steps: goods are transported to the convention center directly or to the warehouse, the goods are handled by the convention center and the goods are sent back or recycled (S. X. Zhang, 2012a).

Since most convention centers prefer a location within an urban environment, the available space around it is limited. Space is of importance to convention centers since that is their main source of income; they sell commercial space to exhibitors. Therefore, they want to increase the commercial space in order to establish a higher income. Besides commercial space, convention centers also need space for other activities such as storage and logistics. If the space for these other activities can be reduced, more commercial space can be established. As mentioned before, the logistics at a convention centers requires many truck movements. If there is unlimited logistic space, handling all these trucks is not a problem. However, this is often not the case.

If there is insufficient space for incoming trucks, this can lead to queues and waiting times for trucks. The emergence of queues is undesirable since they take up space as well. Queues emerge if a system performs poorly. The performance of a queuing system depends on the number of arrivals, the waiting times and serving times. There are several methods to handle queues and to improve performance such as reducing the amount of incoming trucks and speeding up the process (Sztrik, 2016). If methods are applied, queues can be prevented and the needed capacity can be reduced. A reduction in the required capacity means that less space is needed for logistics and more commercial space could be established.

Besides limited space, a location within an urban area has besides the limited space another challenge. The population within urban areas increases. This increase leads to an increase in transportation, which leads to negative side-effects such as pollution, a decrease in road safety and congestion. In order to deal with these negative effects new governmental regulations are implemented such as environmental zones, road pricing and licensing (Quak & Tavasszy, 2011). Convention centers that are located within these urban areas have to conform to these new regulations. To comply with the regulations certain aspects have to be adjusted such as the logistics. Both the transport to and at the convention center should comply with new regulations to improve the environment of the urban area. To achieve this changes should be made within the logistics of convention centers. These changes can reduce the amount of transportation at convention centers and increase the share of zero-emission vehicles. However, these changes require investments and considerable adjustments in logistic processes and possibly the infrastructure.

How convention centers should handle the lack of space and regulations is hard to determine. Limited research has been done into logistics at convention centers. Prior research has been done into the supply chains of convention center. However, research that focuses on requirements and possible designs for efficient and less polluting logistics at convention centers is lacking. With the pressure of emerging regulations within cities it is important for convention centers to modernise and update. By doing this, convention centers will be able to meet the current demand for conventions or even expand while contributing to a pleasant living environment.

1.2 Case Introduction

The RAI Amsterdam is a convention center that hosts around 400 events per year. The RAI has a unique location in the south of Amsterdam. The airport and the city center can be reached within ten minutes (RAI Amsterdam, n.d.-a). The location of the RAI attracts many events and visitors since it ensures good accessibility and provides an easy opportunity for visitors to explore Amsterdam as well. Besides the positive effects of this location, it also causes complex problems. These problems relate to nuisance in the neighbourhood and environmental policies of the municipality of Amsterdam. Another downside is that there is not much space to expand since open space within Amsterdam is limited.

In Figure 1.1 the surroundings of the RAI are shown. The RAI is enclosed by a residential area on the north and east side, a highway and train track on the south side and a recreational park on the west side. The RAI and the residential area on the north side are separated by a road. Because of this proximity residents complain about the nuisance caused by traffic at the RAI. This nuisance consists of noise, visibility and safety. When big events are held there can be over 400 vehicles on a daily basis (Buck Consultants, 2019), these vehicles are mainly trailers, trucks and delivery vans. The amount of vehicles on this road causes unsafe situations due to road blocking, which also leads to congestion. Arrived vehicles unload their goods at the work sites located at the north side. The unloading process causes a considerable amount of noise due to the forklifts that are being used and the dropping and moving of goods. Besides vehicles that come in for logistic purposes there are also taxis and private cars, which make the traffic situation even more hectic.

Figure 1.1: RAI surroundings

The municipality of Amsterdam implemented an environmental zone in 2008 since then the zone has been expanded incrementally and more vehicle types have been excluded. The RAI is still excluded from the environmental zone. Therefore, it is still possible to deliver with trucks and trailers that do not meet the environmental zone requirements. The environmental zone covers the residential area and the recreational park. In the future Amsterdam wants to expand the environmental zones, making it harder to reach the RAI with standard trucks and vehicles (Gemeente Amsterdam, n.d.). The goal is to ban all diesel and gasoline vehicles in the environmental zone in 2030 (Binnenlands Bestuur, 2019). This would impact the RAI since the accessibility for diesel and gasoline trucks and trailers becomes problematic. Apart from the implementation of the environmental zone, the municipality also demands that the RAI actively tries to reduce the nuisance in the neighbourhood (Gemeente Amsterdam, 2018). To deal with these problems, innovating is important to the RAI to ensure a higher sustainability and a satisfied neighbourhood. The vision of the RAI is similar to that of the municipality. The RAI stated that by 2030 all transport at the RAI should be zero-emission (RAI Amsterdam, n.d.-b). They also want to close off the north side for logistics completely. This means that unloading spots at the north side will no longer be available and trucks and trailers will only be allowed to unload at the south side.

Besides dealing with the environment and the neighbourhood, the adjustments should be efficient and the commercial space should increase or remain the same. With the potential closure of the logistic space on the north side the available capacity for trucks and trailers will decrease. Capacity is already tight or insufficient at the RAI during big events. A decrease in capacity would therefore lead to queues and long waiting times. In order to avoid this, the logistic processes should be optimized. Different measures could be implemented such as the reduction of trucks and trailers and improvements in the unloading processes to increase capacity.

An important change that the RAI has made so far is the construction of a buffer area outside the RAI. On busy days vehicles have to register at the buffer before they can enter the RAI. The buffer ensures a controlled flow of trucks and trailers to the RAI, which reduces queues and waiting times at the RAI site (RAI Amsterdam, n.d.-a). However, the queues still exist and there are still waiting times at the buffer area. Moreover, the buffer area is not a solution for the nuisance problem in the neighbourhood. In the future the goal is to manage the arrival of trucks and trailers in such a way that the buffer is no longer needed or only in exceptional situations. This is desirable since the buffer area is located 20 minutes from the RAI. This requires truck drivers to make detours and wait at the buffer area, which is a burden for truck drivers.

1.2.1 Logistics System and Network of the RAI

To get a better understanding, a clarification of the logistic processes is given. First, insight is given into the lay-out of the RAI. In Figure 1.2 the lay-out of the RAI is shown. The RAI can be divided in three parts: the Holland Complex, Congress Centre and the Europe Complex. The Holland Complex is located at the south side and the Europe Complex at the north side. Halls 1 to 7 are located at the north side and halls 8 to 12 at the south side. On the outside the halls are surrounded by work sites. There are five main work sites. On the north side the P8, P9 and P10 are located and at the south side P5A and P5B. At these work sites the unloading of trucks and trailers takes place.

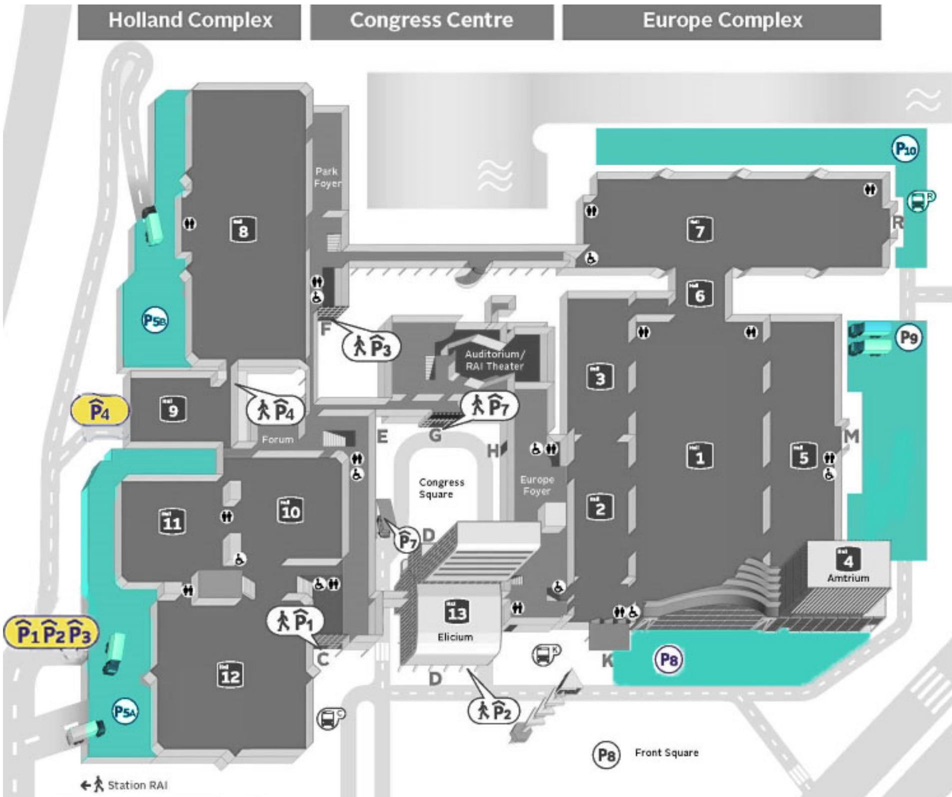


Figure 1.2: Map of the RAI, blue parts are worksites

As mentioned before the RAI works with a buffer area on busy days, which is called P20 or Westpoort. This buffer area is located on the north-west side of Amsterdam. The drive from the buffer to the RAI takes around 20 minutes depending on the traffic situation. The buffer is used on busy days to control the arrivals of trucks and trailers at the RAI. Trucks or trailers that need to use the worksites are obliged to register at the buffer. After registration the vehicle has to wait until it is called and permission is given to drive to the RAI.

For every convention at the RAI a different logistic plan is made since every convention has its own characteristics. Every convention differs with regard to the type of goods, type and amount of vehicles and the build-up and break-down time. There are two main options: a busy convention which uses the buffer and a normal convention which does not use the buffer. In Figure 1.3 the logistic process for a normal day is shown and in Figure 1.4 for a busy day. On normal days vehicles arrive at the north or south side of the RAI and are sent to an unloading spot. The unloading starts and the pallets are transported to the stand, this transportation can be done with a forklift or by hand. On busy days there is a slight difference since the vehicles drive to the buffer first. At the buffer the vehicles have to wait until they get a sign which allows them to enter the RAI. When they arrive at the RAI the same processes as on a normal day take place.

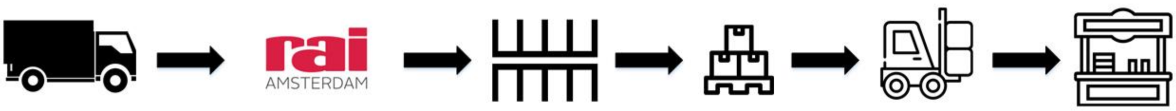


Figure 1.3: Logistic process normal day

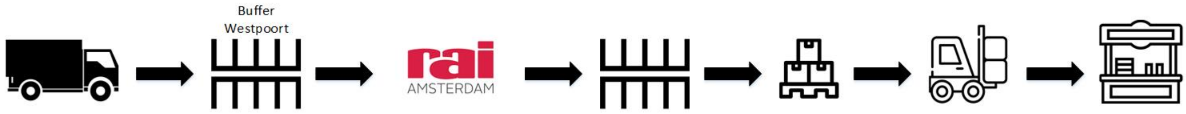


Figure 1.4: Logistic process busy day

Within this research the term logistics system will be often used. A definition of this term will be given.

Logistics System

A logistics system includes besides the transportation network: activities, information, and people. The logistics system is also in charge of inventory management and is not only focused on the transportation (Zhu & Yao, 2011). In other words the logistics system consists of all activities and processes required for the transportation, information and knowledge that is necessary for logistics (Nowicka-Skowron, Nowakowska-Grunt, & Brzozowska, 2018).

The logistics system of the RAI can therefore be described as:

- The logistic network of the RAI, which includes: work sites, buffer area, storage facilities, infrastructure within and outside halls and vehicles for loading and unloading.
- Communication systems within the RAI
- Communication systems with outside parties
- Rules and regulations at the RAI site
- Logistic staff at the RAI
- Logistic IT systems

1.3 Research Problem

The RAI Amsterdam is looking into opportunities to update their logistics system. The three main goals are:

- Improving logistic performance
- Reducing nuisance for the neighbourhood: by closing off logistic space at the north side
- Maintaining commercial space

Adjustments to the logistics system can be implemented on many aspects such as: implementation of new technologies, influencing the behaviour of arriving trucks and trailers and redesigning the infrastructure. The RAI would like to know which changes can be made and how these changes affect external factors, performance and commercial space. Understanding the impact of these changes would allow the RAI to make a better informed decision on the changes they want to implement in order to improve the logistics system.

1.4 Research Scope

This research is focused on the freight logistics of convention centers, in this research the RAI Amsterdam is used as a case. The freight logistics system of the RAI will be studied; however, not the entire system is taken into account, only certain aspects. Including the entire logistics system would make the project too large for a thesis. Therefore, only the most relevant and scientifically interesting aspects are included.

In Figure 1.5 the scope of this research is shown. The green rectangle represents the aspects that are included and the red rectangle represents the aspects that are adjusted during the research.

The research focuses on the build-up process. This decision was made based on two reasons. The first reason is that the data of the build-up showed higher arrival peaks than the data of the break-down. This means that more vehicles want to enter the RAI at the same time, which results in queues. The break-down handles more trucks and trailers per day, however, they are already better spread out over the day, which results in lower arrival peaks and less queues. The second reason is that the behaviour of the build-up is easier to capture than the behaviour of the break-down. During build-up it is clear where all goods should go. On the packaging it says to which stand the goods belong. This makes it easy to deliver the goods to the right stand. During break-down only part of the goods are returned and a part ends up in the rubbish bin. How many goods are returned is unclear. During break-down the goods should be collected, packed and made ready to be loaded before the truck or trailer arrives. If the goods need to be returned it is often unclear to which truck or trailer they belong since this information is not mentioned on the packaging. Because of these reasons the decision was made to start with a research into the build-up of a convention. In the future this research could be extended to the break-down of a convention.

The processes outside the RAI site are not included. These processes include the route to the RAI and the possible processes at the buffer area (Westpoort). This decision was made since including these processes would highly increase the complexity of the research. Also, the main focus is the capacity on the RAI site and not the capacity of the roads outside the RAI. By excluding these aspects, effects on the route such as influence of traffic lights, traffic jams and road closures are not incorporated. However, these could have an effect on the arrival pattern. Also, the capacity of the RAI could influence the situation on access and egress roads. For example: if the capacity of the RAI decreases and queues occur they could block the access roads. Within this research these processes are not incorporated. However, it is interesting to research the effects of these processes in the future.

The redesign of the logistics system is established by changing certain aspects of the processes. For example, the infrastructure lay-out and unloading method can be changed. The decision was made to exclude the infrastructure within the halls since the focus of this study is on the capacity of the working terraces. Infrastructure changes within the halls could have an influence on the delivery time. Future research can be conducted to find out how much delivery time reduction can be established by redesigning the infrastructure within halls.

Besides excluding and including several aspects, it was decided to keep certain aspects unchanged. By stabilising certain characteristics, a clearer picture of the effect of the changes that are made in the system can emerge. The following aspects are kept stable: type of event, type of vehicles that deliver goods and type of goods. The RAI hosts almost 400 events every year. Large events occupy the entire RAI whereas smaller events occupy one or two halls. When smaller events are taking place they are often combined, which means multiple events take place at the same time. By doing this, the RAI can still use a high percentage of the commercial space when smaller events are held. Therefore, the type of event used in this research is assumed to be an event that occupies all halls within the RAI. The work sites can only be used by trucks and trailers, personal vehicles and vans are not included. The goods that arrive are all delivered on pallets and have the same dimensions. Normally, arriving goods have a variety of dimensions.

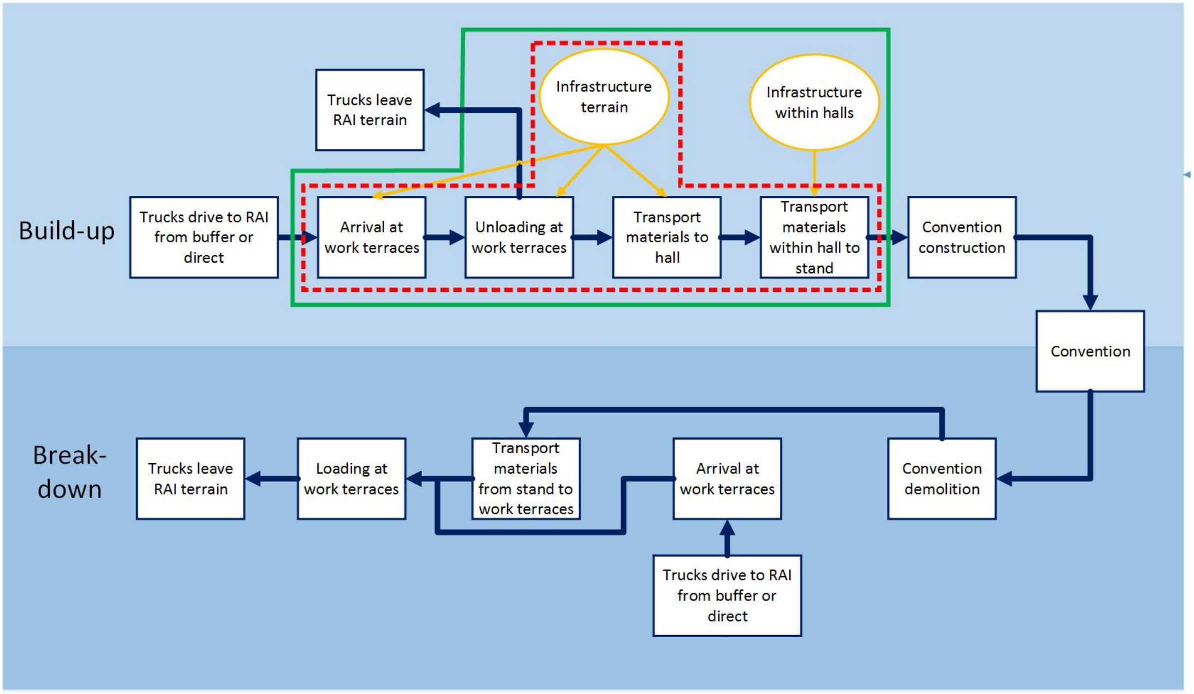


Figure 1.5: Research scope

1.5 Research Objective

The objective of this research has two sides: a general more theoretical approach on how convention centers can improve their logistics system and a more specific practical approach for the case of the RAI Amsterdam .

The theoretical approach focuses on how convention centers in general can improve their logistics system regarding performance and commercial space. All convention centers have to deal with logistics in order to organise events. However, limited research has been done into this subject. This research tries to add valuable information on the subject of logistics at convention centers.

The practical aim of this research is to determine how the RAI should adjust their logistics system in order to improve performance and comply with regulations to reduce nuisance for the neighbourhood. In this research multiple designs of the logistics system will be evaluated in terms of nuisance, performance and commercial space. The goal is to find a design that increases the performance, maintains or increases commercial space and reduces the nuisance best. More in detail, the design should improve unloading times, loading times and delivery times. The total number of vehicles for unloading and transportation of goods should be credible. And the logistic space should be minimised since this takes up space that could be used for other activities. Besides these requirements there are also constraints that should be taken into account. Finding a design that complies with these requirements and constraints can ensure that the RAI will be able to maintain a high performance with reduced negative external effects in the future.

1.6 Research Questions

In order to give an answer to the research objective the following research question is defined.

How can the RAI redesign the freight logistics system to reduce negative external effects, improve logistic performance and maintain commercial space?

To answer the main research question the following sub-questions are defined.

1. Which logistic problems are convention centers facing?
2. Which technologies and strategies can be used to improve logistic performance at convention centers or similar industries?
3. How is freight currently transported to, from and within the RAI and why is it not optimal?
4. How does the current logistics system affect performance, nuisance and space?
5. Which logistics system designs can be implemented and how do they affect the performance, nuisance and space?
6. Which factors are decisive for the optimal logistics system of a convention center?

1.7 Research Approach

To structure a design process multiple methods can be used. A common method is design for Six Sigma. Two alternatives exist, namely DMADV and DMAIC. Six sigma is a measurement of quality and focuses on improving processes and products. Over the years six sigma improved efficiency, effectiveness and innovation in various industries (Jenab, Wu, & Moslehpour, 2018). DMAIC consists of the following phases: define, measure, analyse, improve and control. This alternative is mostly used for systems that are already in operation and when improvements of certain aspects of this system need to be made. DMADV consists of the phases: define, measure, analyse, design and verify/evaluate. This alternative is used for the redesign of systems or designing completely new systems (H. Wang, 2008).

Many logistic processes already exist at the RAI and improving these processes would suggest the usage of DMAIC. However, besides the existing processes new processes and strategies are included. These new strategies and processes are for example including a truck appointment system, implementing new options for unloading and redesigning the infrastructure. DMAIC improves the current processes and controls the process performance often by studying the real-world system. However, studying the real-world system at the RAI is not possible. The logistics system is facing changes on various aspects within the design, and implementation of the system during the research is practically impossible. Because of these reasons the decision was made to work with Six Sigma DMADV. The phases of the DMADV consists of the following five aspect. First, the needs of the customer and the reason for the project are defined. Second, the performance of the current system is measured. Third, after measuring the system it is analysed. Fourth, based on the previous steps a design is made. Finally, the design is verified to check if the needs of the customer are met, and the designs are evaluated to see which one scores best. (Graves, n.d.). Within this research the following phases are defined and an overview on how these phases help answer the research questions is given in Figure 1.6:

- **Define:** A definition is given on the reason of the project. The problem of the RAI Amsterdam is defined. And technologies and systems that could be of interest are explored. Gives an answer on sub-question 1 and 2.
- **Measure:** Data related to the system is gathered. This data is used to measure the system. A description of the current situation is given and the key performance indicators are introduced that are used to measure the performance. This phase gives insights in the current functioning of the logistic processes. Gives an answer on sub-question 3.
- **Analyse:** The found measurements of the current logistics system are analysed. This gives insight in the current performance and shows where improvements can be made. Gives an answer on sub-question 4.
- **Design:**Different designs are made of various options and the performance of these designs are researched. The factors that determine an optimal logistics system are researched as well. The designs are specialised for the RAI Amsterdam. Gives an answer on sub-question 5.
- **Evaluate:** Outcomes are verified and conclusions and recommendations can be given. Answers sub-question 6 and the main research question.

1.8 Research Methodologies

To be able to define the system and gain insight into convention center logistics, a literature study is performed. Literature on convention centers and other industries is studied to obtain an overview of technologies and strategies that can be used to improve logistics at convention centers. The literature study will answer sub-question 1 and 2. Besides the literature study the interviews of several stakeholders will be used to answer sub-question 1 as well.

The measure phase focuses on how the current system works and how the system performance is determined. First a description of the current system is given and a stake holder analysis is performed. The current system will describe how the logistic processes at the RAI are executed. To be able to measure the performance of the current situation key performance indicators are introduced. Based on these key performance indicators data is collected. Data is partly collected from the RAI and partly measured within the field. The measure phase will answer sub-question 3.

In the analyse phase the obtained measurements are analysed. For the analysis excel will be used since the amount of data is easy to handle with this program. The performance of the current system will be studied with the use of a simulation model in which the outcomes of the data analysis will be used. For the simulation model Discrete Event Simulation (DES) will be used. The logistic processes will be simulated starting from the arrival at the RAI until the departure. The outcomes of the simulation model will be used to validate and verify the model. The analyse phase will answer sub-question 4.

After analysis of the current system the system requirements, to which new designs should comply, are introduced. The requirements are based on interviews with different stakeholder that are involved in the logistics at the RAI. Based on these requirements different designs are formed for the future system. These designs will be simulated with the use of the DES simulation model. With the simulation outcomes and the requirement analysis sub-question 5 will be answered.

The simulation outcomes of the different designs will be evaluated with the use of the Analytical Hierarchy Process (AHP), this is a form of multi criteria decision analysis. With the outcomes of the AHP sub-question 6 can be answered. Based on the simulation results and the AHP outcomes conclusions can be drawn and recommendations are given. This will answer the main research question.

A broader overview of the methodologies can be found in section 2.9. An overview of the methodologies and how they relate to the research questions can be seen in Figure 1.6

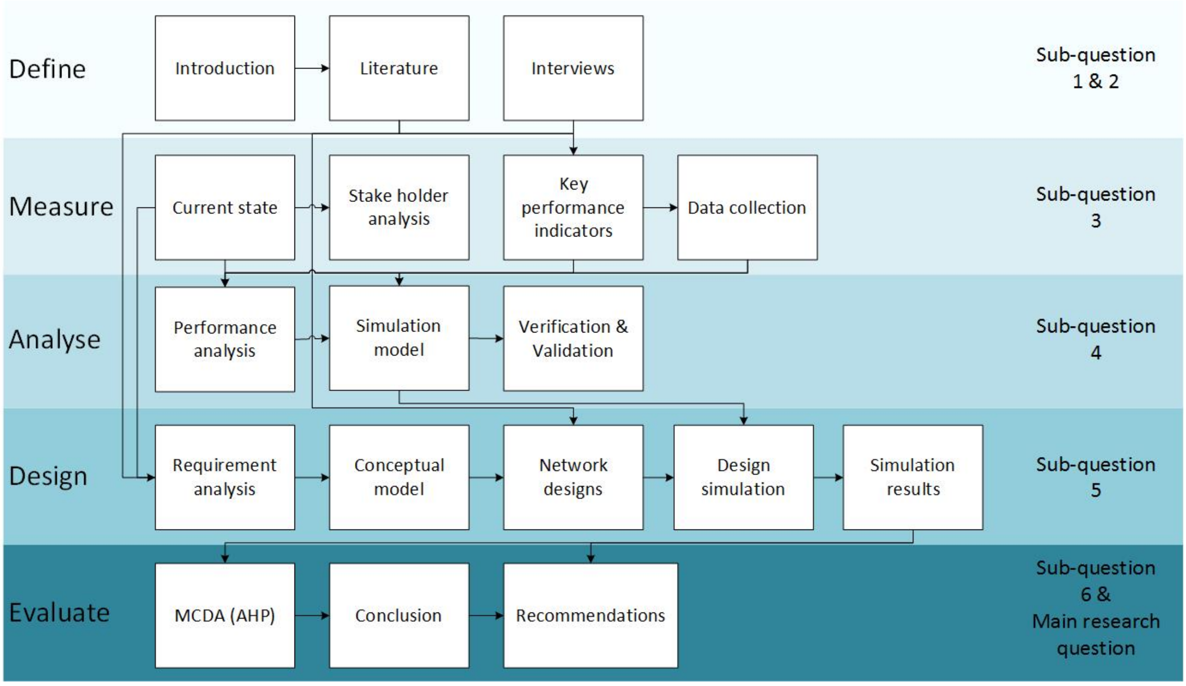


Figure 1.6: Research overview

2 | Literature

In this chapter the literature on convention centers will be discussed. Since there is only limited research on convention centers there is looked into different industries as well. The four studied industries are mass-events, city logistics, warehouses and ports. Technologies and strategies that were found within these industries and could be of interest for convention centers are further researched. These outcomes will answer sub-question 1 & 2 (section 1.6).

After the discussion of literature in other industries the methodologies used in this research will be discussed. These methodologies are: queuing theory, literature study, interviews, conceptual model, modelling techniques and simulation, requirement analysis and multi criteria decision analysis.

2.1 Convention Center Logistics

There is limited research on convention center logistics; however, a few researches focused on the supply chain of convention centers.

Zhang (2012a) defined three main characteristics for convention center logistics. These characteristics are that it is security accuracy demanding, highly complex and it requires good information. Security accuracy demanding means that there should be no damage to the transported goods and that they should be on time. The logistics process control is complex since transport includes transporting, storage, handling and warehousing and it has an information technology requirement. This means that there should be real-time monitoring to adjust specific actions in the process. Haixia (2010) found that these characteristics make convention center logistics complex. The reasons for the high complexity are: exhibits/stands are diverse and have small volumes, planning is complicated due to all different actions(packing, loading, unloading, storing, etc.) and back-haul logistics. Back-haul logistics means that some exhibits/stands have a two way flow so a return delivery as well.

The supply chain of a convention center is relatively short; however, it differs for every event. Goods are send from exhibitors to a warehouse/storage and are then transferred to the venue. In the end the goods are send back to the owner or a different party (S. X. Zhang, 2012b). In Figure 2.1 the supply chain is shown for exhibitions. This supply chain only specifies the actions for the exhibits. However a convention center has more deliveries coming in, for example construction materials, food and drinks. The supply chain for these materials differ since food and drinks have no return delivery they end up being eaten and partly in the rubbish bin. Construction materials can be re-used for the next convention. If this is not the case they need to be stored, transported back or thrown away. Convention centers have to deal with a lot of different goods coming in and going out, all with their own characteristics. A high diversity of goods increases the complexity of the logistics system (Handfield, 2013).

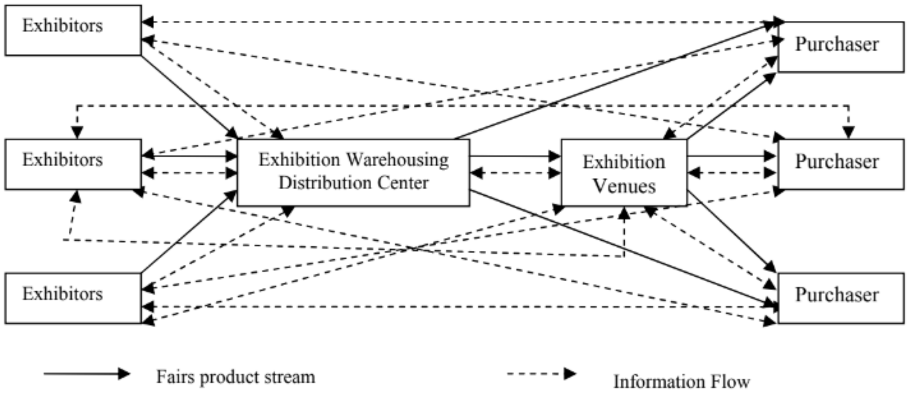


Figure 2.1: Logistics Supply Chain System (Zhang, 2012a)

To deal with complex logistics several methods are introduced. Zhang (2012a) suggest the use of radio frequency identification (RFID). RFID is an easy way to receive information about incoming goods and the corresponding destination of the goods. Besides identifying goods RFID can also be used on vehicles. This way vehicles and their loads can be located, identified and it can quickly be seen where these vehicles need to go.

Haixia (2010) states that outsourcing is a good way to overcome problems in convention center logistics. These problems are a mismatch between supply and demand, bad service, lack of professionals and a poor flow of information. Outsourcing means that one or two companies take care of all the logistics and not the convention center itself. In this way some of the problems become easier to handle. Outsourcing can lead to scale economies effect, reduce costs, shorten and simplify the information flow, and increase logistic efficiency. However, there are still some obstacles for outsourcing as well. These obstacles are the lack of overall planning, imperfection in service and only a few enterprises having the capacity of outsourcing.

Ju (2011) gives a more global overview on how convention centers can develop their logistics to become more efficient and modern. Four methods are introduced in the research. Firstly, a professional brand should be established, this means that a high quality service should be guaranteed. By establishing high quality the convention center can distinguish itself from others. Secondly, there should be innovation on technology and services. Innovation in transport could make the transportation safer and faster and innovation in storage can improve the quality of it. This also improves the competitive advantage from the convention center. Thirdly, information management should be efficient. A good information system improves management and lowers costs. And the last method is the control of the costs of logistics. Costs should be controlled and managed at each step of a convention to see where improvements can be made.

2.1.1 Characteristics of Logistic Lay-out

To find out how most convention center handle their logistics multiple convention centers are researched. The convention centers taken into account are located within Europe and America. Finding information on convention centers in other continents turned out to be difficult. The found information on logistics is retrieved from the websites of the convention centers. All convention centers offered logistic services, the range of these services vary for every convention center. The use of a main logistic partner, who is responsible for logistics on the site of the convention center is common. All studied convention centers in the Netherlands and Germany used one or two main logistic partners. In most cases the logistic partners are the only ones that are allowed to operate forklifts and other motorized equipment. Before trucks and trailers are allowed to enter the convention center site they have to sign up. Convention centers have different sign up methods. At a few convention centers the sign up had to be done online prior to the arrival of the truck and trailer. However, at most convention centers the sign up is done at the arrival of the truck and trailer before they enter the site. Convention centers exist mostly of large exhibition halls, large convention halls and smaller halls. In order to have a good connection to these halls convention centers have multiple entries for trucks and trailers. These entries are located on different sides of the convention center site near large halls. Larger halls require more goods and equipment and therefore need more trucks and trailers. The unloading of trucks and trailers takes place on the outside space around the halls. A few convention centers have a very spacious set-up, which ensures enough unloading space. However, convention centers with less space often use a buffer or waiting area for trucks and trailers. If trucks and trailers arrive they first have to sign in at the waiting area. They wait at this area until a unloading spot is available. In the best cases these waiting areas are located within close proximity of the convention centers. However, in certain cases such as the RAI the waiting area is located 20 minutes from the RAI. These waiting areas reduce the chances of queues on the convention center site.

Overall most convention centers have the same logistic set-up. They have multiple entry points that makes it easy to reach all halls. Near the halls unloading spots are created in order to unload trucks and trailers. For the unloading of trucks and trailers forklifts are used by the logistic partner. In cases where the logistic partner is not used the unloading is done by hand. Depending on the amount of space and the amount of incoming trucks and trailers a waiting area is required. Convention centers that have limited space use this waiting areas to regulate the amount of trucks and trailers on the site.

2.2 Interviews RAI

Since literature is limited on the subject of convention center logistics several interviews were conducted. For these interviews employees of different departments of the RAI were chosen to participate to get an overall view on the logistics of a convention center. The interviews can be found in Appendix C. The interviews are used to obtain full insights in convention center logistics.

From the interviews it came forward that convention center logistics is time-critical this means that there is only a limited amount of time to build or break-down a convention. The logistics should be able to handle these time-critical events. Besides being able to handle the time-critical aspect the logistics should also be flexible. This means that the logistic plan should be adjustable for every convention and is able to handle disruptions.

Another important aspect is the share of information. In the interviews it was often stated that there is a lack of communication especially from the deliverers to the RAI and vice versa. This causes chaotic situations and leads to many vehicles showing up at the same time causing high arrival peaks. In the past the RAI already made some changes regarding logistics. They found that it was hard to convince all involved parties that these changes were necessary. Not all involved parties were willing to adopt to these changes.

Within the interviews several reasons came forward why the current logistics should be adjusted. These reasons are nuisance, environmental issues and the lack of space. The neighbourhood is complaining about the nuisance caused by logistics. The municipality agrees with the neighbourhood and is also forcing the RAI to become more environmental friendly, with the of an environmental zone. The RAI has limited available space since it is located within a city. Due to the expansion of exhibition halls the logistic space is even decreased further. In the future the RAI wants to expand halls even further and redesign the outside space to parks. These changes will reduce the available logistic space even further. With the logistic space that is available now the build-up and break-down of certain conventions is already critical. A further reduction in logistic space will increase these problems and can lead to delays in the build-up and break-down. Therefore, logistics should be arranged in a smarter way without reducing the commercial space and still allow conventions to build-up and break-down within the given time.

2.2.1 Research Gap

After the literature study to convention center logistics it can be concluded that available literature on this subject is limited. The literature gave some useful insights on how convention centers could improve their supply chain. These methods are the help of IT systems such as RFID and outsourcing. How and why convention centers can improve the performance of their logistics system is not described within the literature. Since literature is limited interviews were conducted. These interviews gave insights in the current logistics and why the logistics should be adjusted. Logistics at convention centers should be time-critical and flexible. Improvements can be made on communication to involved parties. Reasons to adjust logistics are nuisance, environmental issues and space. Improving the performance of the logistics system is important to reduce the required space and nuisance and still allow the build-up and break-down of all conventions. A high performing system has almost no queues and waiting times. Since there is no literature on how convention centers can improve performance of their logistics system this is the research gap that is filled in this research. This research gap led to the main research question: *How can the RAI redesign the freight logistics system to reduce negative external effects, improve logistic performance and maintain commercial space?*

2.3 Other Industries

Since literature on convention centers is limited four industries are researched, which show similarities to convention centers. They handle incoming trucks and trailers and have to unload them. In order to avoid queues and waiting times these industries implied several methods. The studied industries are warehouses and distribution centers, city logistics, ports and mass events. Literature is used to see how these industries handle incoming trucks and trailers and how they speed up the process.

Warehousing and distribution centers show similarities with convention centers since these consists of big halls where products need to be picked-up and delivered. They also show similarities regarding vehicles coming in to deliver or pick-up goods. They have to deal with the same problem as the convention center since many vehicles may come in at the same time when there is no place available. City logistics focuses on logistics within cities since several convention centers are located within cities this is also an important aspect for the logistics at the convention center. Ports show similarities in the arriving process of vehicles, they also struggle with the fact that vehicles should only come in when they are needed. Mass events have similarities when it comes to the process of building-up and breaking-down an event and the large amount of goods that have to be transported.

2.3.1 Mass Events

Mass events have a build-up phase and a break-down phase like conventions. However the big difference is that for conventions the same location is used and for mass events different locations are used every time. This means that the infrastructure around a mass event is mostly not designed with the event as its main goal.

Logistics is one of the crucial fundamentals for a mass event to take place. The set-up of the logistics network has an impact on the organization of the event. The following components are of importance for mass events: transport routes, means of spatial transport, buildings, warehouses and storage facilities (Dziadkiewicz, Kadlubek, Legowik-swiacik, & Baskiewicz, 2016).

Research about the logistics operations at the Olympic games divided the logistics system in four subjects: venue logistics, asset tracking, warehousing and distribution and freight forwarding and customs clearance. Venue logistics includes identification of requirements for the venues and the dock management including delivery scheduling. Asset tracking is used for delivery coordination and can be accomplished by different technologies or coding systems. Warehousing and distribution is often outsourced at the Olympic games. Outsourcing is more efficient because the hired company already has the right equipment and experienced staff. Setting up a warehouse from scratch and train staff is more expensive and time consuming than hiring a company. The same applies to freight forwarding and customs clearance, this should be done by an experienced international forwarder (Minis, Paraschi, & Tzimourtas, 2006).

Another research focused on the design of the venue logistics for a World Exposition (Creazza, Colicchia, & Dallari, 2015). A World Exposition deals with a lot of different clients and exhibitors who have different requirements. Similar as in a convention center there is a huge variety of services and goods to handle. For the design of the venue logistics it is important to know the requirements for the system. An optimised design is one that compresses costs, no unnecessary assets should be constructed or bought. On the location there needs to be space for logistics; however, not more than necessary. The required space for a warehouse is based on parking space and the trailer court, an inbound area including unloading docks, a cross-docking area, an outbound area including loading docks and areas including additional storage space. Predictions should be made for the required space prior to constructing.

2.3.2 City Logistics

Cities are getting more crowded and city logistics is finding a way to deal with this. Since the population in these cities increases the amount of transportation increases as well. This leads to an increase in congestion on city roads. Congestion can be seen as an queue since it consists of vehicles that are waiting to enter or exit a certain area. Research on city logistics tries to find efficient ways to transport goods within cities. The focus is to reduce negative eternal impacts like congestion, pollution and safety. (Savelsbergh & van Woensel, 2016). There is still much improving to do for city logistics. More than 40% of the atmospheric contamination's and traffic hazards are caused by city logistics. There are a many innovations that try to reduce these negative externalities and improve sustainability of cities. These innovations are: the use of electric vehicles, off-peak hour delivery, consolidation of vehicles and goods and underground freight transport (Hu, Dong, Hwang, Ren, & Chen, 2019). In order to make logistics sustainable and future prove logistics must be highly efficient, reliable, safe, environmental friendly and cost-effective. An important aspect to achieve this is a better utilisation of existing infrastructures. In certain cases acceptation has to be made on the fact that new systems cannot always be cost-effective (Clausen, de Bock, & Lu, 2016).

Within cities transportation is taking place every day an at every hour. There are different kinds of transportation such as private transportation and freight transportation. Freight transportation accounts for 25% of the street traffic within cities. Other impacts from freight transportation is that it requires space (Dablanc, 2007). When goods are delivered they have to be loaded and unloaded this means that vehicles mostly trucks and vans have to stop within the city, preferably on a parking spot. However, this is not always possible and vehicles are often forced to stop on pavements or streets, which causes congestion and unsafe traffic situations. Goods that have been delivered need storage this takes up space that could be used for other activities within the city.

Freight transport within cities is the final part of the whole transportation route. This distance is also called the last mile, which is known as the least efficient section of transport. To deal with the problem of last mile distribution development is made on information and communication technologies and new transportation vehicles. In literature the following innovations are found (Ranieri, Digiesi, Silvestri, & Roccotelli, 2018):

- **Innovative vehicles:** introduction of electric, hybrid and fuel cell electric vehicles. These vehicles reduce negative externalities like noise and environmental pollution. A main constraint of electric vehicles is that they need time to recharge when empty. Another innovation is autonomous vehicles that can operate without human intervention. Autonomous vehicles can operate on different terrains such as: road, water and also air.

- **Collaborative and cooperative urban logistics:** much research has been done into combining the loads of multiple vehicles into one vehicle. Combining loads reduces the number of vehicles that need to make deliveries within cities. Combining loads from different vehicles occurs at a certain place mostly a distribution center or a warehouse.

- **Innovations in public policies and infrastructures:** adjustments to infrastructure can improve traffic flow and reduce congestion. This can be done by implementing smart traffic light management, separation of traffic and the introduction of time windows. Time windows can reduce freight traffic within the city at rush hour times and therefore reduce congestion within rush hours.

2.3.3 Warehouses and Distribution Centers

Distribution centers and warehouses are facilities that are able to process, store and distribute goods. The goal of distribution centers is to make transportation more efficient. Distribution centers are built with the purpose of storing goods till they are needed. Companies with a distribution center can improve responding speed and reduce inventory costs. The location and the layout of the distribution center are of great importance on the performance of it (Wan, Guan, & Shao, 2011). The goal of a warehouse is slightly different since it is used to control the inventory and to smooth out fluctuation in supply and demand. However, the layouts of distribution centers and warehouses are to a certain extend similar. Warehouses and distribution centers are both developed to store goods, the more goods need to be stored the bigger the warehouse or distribution center should be. In order to reduce the amount of stored goods and thus reduce space cross-docking can be implemented. Cross-docking means that delivered goods are immediately packed on to the next truck without storing them in the warehouse or distribution center. This method asks for a controlled environment. A detailed vehicle schedule is required, which links trucks together. To achieve this IT systems should be used (Yu & Egbelu, 2008). If a truck or trailer arrives too early it has to wait, which takes up space and if it is too late the goods have to be stored. If the waiting trucks are occupying unloading spots this can lead to queues of trucks and trailers waited to be loaded or unloaded.

A common physical configuration for a warehouse or distribution center consists of the following components: set of gates where trucks unload and load, a sorting area to process goods and a buffer area where goods can be stored temporally. If warehouses work with automated guided vehicles (AGVs) more infrastructural components are required such as a recharging area, set of AGVs and infrastructure for navigation. The layout of these components can have a significant impact on costs and productivity. Layouts of warehouses are depending on characteristics such as: production variety, volumes, number of floors and the material handling system that is used. The choice of the material-handling system can have a major influence on the operating costs, it represents 20-50%. It also has a huge influence on the layout of the warehouse or distribution center. Due to these reasons choosing the right material-handling device is an important aspect within warehouses (Ribino, Cossentino, Lodato, & Lopes, 2018). Handling devices that are commonly used in warehouses and distribution centers are: forklifts, EPTs, AGVs, conveyors and other handling types. Layouts for warehouses can influence the travel times for these vehicles. A short travel time is preferred since this reduces costs and increases system performance. An efficient layout of the work floor within a warehouse or distribution center can reduce travel distances up to 10%-15% (Li & Liu, 2018).

2.3.4 Ports

A port connects overseas transport with the hinterland. Container transport has increased the last few years, which resulted in port congestion. Arriving containers need to be shipped from the port to the final location on land, this transport can be done by truck, rail or inland shipping. Port congestion can reduce the performance and the success of a port. There are many methods to measure the performance of ports. Two frequent ways of measuring port performance are efficiency and cargo throughput. The success of the port is influenced by the performance and by its location. A port on a location with good access to rail and road transport, is near customers, has deep-sea access and provides frequent and global services of shipping is more likely to have success (Felício, Caldeirinha, & Dionísio, 2015).

Port congestion occurs when trucks have to wait at the port on their container. This congestion leads to long truck turn times, decreases the performance and increases air pollution. One way to avoid truck congestion is increasing the capacity. This can be done by increasing the number of gates, cranes and the amount of storage space. However expansion is expensive and most ports have limited space for expansion. To increase truck capacity without expanding different management strategies are developed such as time windows, truck toll systems and truck appointment systems. These system improve the use of the gate capacity and keep truck waiting times within reasonable limits (H. Zhang, Zhang, & Chen, 2019).

The use of time windows works as follows: two time windows are assigned to a vessel for pickups and deliveries. Trucks that need a container from that vessel deliver or pick up the container at the dedicated time-slot. The main purpose is to reduce the time a container stays in storage. A side benefit is that all trucks with containers for a certain vessel arrive within the time window of that vessel. The use of time windows decreases peak behaviour and truck waiting times besides improving the available storage space (G. Chen, Govindan, & Yang, 2013).

The truck toll system is used to reduce the amount of trucks on peak times. It combines time windows for trucks with road pricing. During peak hours trucks have to pay an extra fee. This extra fee should shift a certain percentage of vehicles to non-peak hours. Implementing a system like this could introduce new problems such as congestion at parking spots and roads near terminals (H. Zhang et al., 2019)

A truck appointment system is focused on receiving information on truck arrival times and patterns in advance. With the use of this information a better planning can be established that reduces waiting times and congestion. To receive this information in advance the number of time-slot should be known beforehand in such a way that truck drivers are aware of this (Caballini, Mar-Ortiz, Gracia, & Sacone, 2018).

2.3.5 Conclusion

Within the different industries several technologies and strategies came forward to improve network and logistics system performance. Mass events focus on the design of the venue to improve the performance and mentioned the use of outsourcing. City logistics has found several ways to improve the downsides of freight traffic within cities with the use of separation of traffic, underground traffic, innovation in vehicles and time windows. The optimisation in warehouses and distribution centers are depending on the layout which includes paths, the docking process, IT systems and the material handling equipment. Ports try to reduce their truck congestion with the use of time windows and truck appointment systems.

The following technologies and strategies are chosen for further research: truck appointment system, IT systems, automated vehicles, conveyor belts, cross-docking and underground logistics.

2.4 IT Systems

Logistics can be improved with better communication between suppliers and customers. This can be achieved with the use of IT systems. With the use of IT systems more information about incoming vehicles and their loads can be gathered. Collected data can be analysed, which can identify specific patterns, trends and system failures. IT can also be used for information-sensing systems like GPS, barcode scans and RFID-tags, with these kind of technologies more information is retrieved and easily shared like position of vehicles and location of goods. In the future more and more systems will be connected also called "internet of things" the systems can connect independent and human intervention is not required anymore (Clausen et al., 2016).

IT systems can also be used to control the arrival process of vehicles. These systems are often used in ports and are called truck appointment systems. Within the industry of convention centers a few convention centers have implemented a system like this.

A more elaborate explanation on RFID technology and the truck appointment systems are given within this chapter. Also, the implementation of several IT systems at convention centers are discussed.

2.4.1 RFID

RFID is a technology that is often used in warehouses. With the use of RFID different objects can be quickly identified and located. Different tags can be used such as pallet tags, warehouse position tags, good tags and many more (Yan, Chen, & Meng, 2008-). RFID uses radio waves to exchange information. This increases the identification speed compared to the use of barcodes since these have to be manual scanned and the barcode has to be visible for the scanner. RFID has three characteristics it is wireless, it has an unique identification for every tag and is able to trace objects with a tag. Research to the implementation of RFID within warehouses showed that it could reduce material handling equipment, inspection time, receiving time, loading/unloading time and waiting time. This increases the productivity of the warehouse and reduces labour costs. Research showed that the number of pallets processed by an operator increased from 8 to 42 pallets per hour. The total process time of objects was reduced from 210 minutes using normal barcodes to 30 minutes with the use of RFID. This increase in throughput per operator makes it possible to deliver the same service with less operators (J. C. Chen et al., 2011). There are three main types of RFID tags passive, active and semi-passive tags. Active tags have a battery and are able to send information without a reader, this makes active tags suitable for transmission of the location of the tag. Passive tags need energy from a reader to send information. The advantage of passive tags is that they are cheap compared to the active tags. The newest developed tag is the semi-passive tag, they have a small battery on board that enables them to ensure a bigger reading range and reliability than passive tags. Semi-passive tags still need a reader to interact with when it comes to location determination (Hassan, Ali, & Aktas, 2011).

Besides tags, antennas and readers a wireless LAN connection is required to determine location of objects. With the use of RFID in location determination large quantities of data can be collected, and with the use of a system this data can be updated, which reduces the workload. The efficiency and accuracy of the warehouse will improve and costs can be reduced (Yan et al., 2008-).

A disadvantage of IT systems are the vulnerability to malfunctions and hackers. The network should be well secured to avoid hackers taking over the system. Also, malfunctions can occur in the LAN connection, antennas and readers. This can lead to a poor working system or the system being down for a certain amount of time. The logistics is depending on the IT systems and when these systems are not working logistics can be delayed or it can come to a complete stop.

2.4.2 Truck Appointment System

Vehicle scheduling is an important issue within logistics. In the ideal situation the vehicle arrives at the location when it is needed. However, in practice this is often not the case. A method to improve this is using a truck appointment system. Truck appointment systems are used in environments that show peak behaviour where the available capacity is exceeded which leads to congestion.

The last decades much research has been done into truck appointment systems especially for port terminals. Most ports work with a truck appointment system, this means that trucks have to choose a time-slot for loading and unloading at the terminal. These time-slots only allow a certain amount of trucks and trailers coming in at that specific time-slot. Different truck appointment systems exist with their own characteristics. A good functioning truck appointment system has to handle different situations such as: missed appointments, late arrivals, cancellations and last minute customers. There are several ways to deal with these situations for example a two-stage reservation confirmation system. When a truck driver books a time-slot in advance he has to confirm the slot two hours before arrival. Another option is implementing fees and penalties, popular times can be more expensive to stimulate the use of less popular times. Missed appointments can be punished with a penalty. A truck appointment system should be able to track the time and the location of the trucks, this can be done with the use of RFID systems, Bluetooth or GPS units (Huynh, Smith, & Harder, 2016).

The use of time-slots reduces the freedom of the driver and it increases the control on the amount of incoming vehicles. With this control queues and waiting times can be reduced. Extensive waiting times are unpleasant for operations and for the truck drivers. Reasons for the problems of queuing and waiting times are: lack of capacity, short opening times, seasonal variations in the freight and temporary breakdowns in loading and unloading equipment (Friswell & Williamson, 2019). Truckers can choose one of the available time-slots for loading and unloading, thereby the operator knows how many vehicles come in and is able to control the truck arrival rates in such a way that waiting times remain acceptable (Huynh et al., 2016). The operators can decide on the amount of time-slots and the amount of allowed trucks and trailers during this time-slot.

A truck appointment systems consists of the following features:

- Web based: Appointment systems can be used on computers and in certain cases also on mobile devices.
- Appointment windows: The time a truck is allowed to arrive at the terminal can vary from half an hour up to days.
- Grace period: Offers some flexibility to the driver. If the driver is late within the grace period entrance is still given.
- Appointment lead time: the cutoff time before making an appointment can vary from days up to minutes.
- Fees: If the truck is late and does not show up at the dedicated time slot a fee can be given. However a fee can also be given to operators if waiting times are too long.
- Peak period appointment fees: Trucks that want to arrive at peak times pay an extra fee.

Truck appointment systems have in most cases a positive influence on the performance of a terminal. However, the literature on these systems showed several shortcoming of trucks appointment systems. These shortcomings are (Huynh et al., 2016):

- Insufficient appointments: Truck drivers claim that the system did not provide enough options for appointments. Due to this fact truck drivers are not always able to pick up loads.
- Lack of flexibility: Not all appointment systems handle appointment changes well. Also, the possibility to pick up multiple containers at different terminals is not always included.
- Vulnerability to manipulation: Truck drivers and companies can reserve more time-slots than they need and can sell these slots to other companies.
- Lack of standardization

When the decision is made to implement a truck appointment system the first step is to determine the operational needs. The most important questions that needs to be answered are: What are the optimal values for the duration of the appointment and grace period? What are the costs to trucking industries? How should fees and penalties be structured? (Huynh et al., 2016)

Convention center struggle with the same problems as ports. They suffer from peak-behaviour and trucks arriving when they are not needed. A truck appointment system can decrease peaks and improve the control of arriving vehicles. If the peak are reduced trucks are spread over other hours, making these hours busier. A truck appointment system has the benefit of receiving information beforehand. With this information a better estimation can be made on the amount of incoming trucks and trailers. The number of staff and forklifts can be adjusted to the available information.

2.4.3 Appointment Systems at Convention Centers

Several convention centers have implemented system comparable to a truck appointment system. Three examples will be given.

The convention center Messe in Munich uses an app called Fairlog. Fairlog is a time slot management system and is only used for trucks and trailers that are longer than 8 meters. Transporters can reserve a time slot for loading and unloading on the app. When they register for a time slot they also have to provide the following information hall number, stand number and the load volume of the vehicle. The driver of the truck with a reserved spot has to check-in 30 minutes before the slot. Fairlog keeps track of the available space in the loading yard, as soon as a space is free the driver will receive a message that says he can drive to the assigned spot. Trucks or trailers that come unannounced register for a time slot on arrival. However, the trucks and trailers with a time-slot get priority (Messe Muenchen, n.d.).

Messe Frankfurt works with an online registration systems. Every vehicle that wants to load or unload has to register online with a registration form, this is mandatory for all vehicles. Only vehicles that are registered have permission to enter the terrain. Vehicles that check in have two scenarios the first scenario is that the vehicle is allowed to go directly to the loading/unloading location, the second scenario is that the vehicle has to go to a buffer space. The vehicle has to wait at the buffer and receives a text when space at the loading/unloading area is available. The loading and unloading processes can be executed by the driver or by the logistic team of Messe Frankfurt. The logistic team is the only company that is allowed to drive forklifts and other motorized vehicles. Besides this registration system Messe Frankfurt also uses cargo centers. They have two cargo centers on site where goods can be delivered (Messe Frankfurt, n.d.).

In London convention center Olympia works with a preregister system. It is similar to the systems in Frankfurt and Munich. All vehicles are obliged to register to a certain time slot. This can be done online or with the app, which is called Voyage Control. Voyage Control is not only used by Olympia but by multiple other convention centers all over the world. Voyage Control shows available time slots, which can be chosen. A driver can pick any of the available time slots and fills in the required information such as the load of the vehicle, license plate and driver information. After booking the time slot an online access pass is send, without this pass it is not possible to enter the terrain (Olympia London, n.d.).

With the use of registration systems such as Voyage Control and Fairlog an overview of the expected vehicles and loads is obtained. This information makes it easier to adjust the logistics to the required capacity. It also limits the amount of trucks coming in at a certain time point. This reduces the chance of queues and waiting times at the convention terrain. Another benefit is that vehicles drive immediately to the right place, this reduces the time that the vehicle is on the terrain. If the RAI would like to implement a system like this, it is important that this is clearly communicated to all involved parties. A appointment system could highly improve the information flow at the RAI and reduce queues and waiting times.

2.5 Automated Vehicles

Implementing automation within a warehouse can increase the productivity, consistency of processes and lower labour costs and human mistakes. Automated vehicles are driver less vehicles that are controlled by a computer system. Several types of automated vehicles exists such as Automated Guided Vehicles (AGVs) and Rail Guided Vehicles (RGVs).

AGVs use predefined paths to move from one location to another. Certain types of AGVs are also able to load and unload goods automatically. To avoid collisions between vehicles different measures exists, sensors can be used on a vehicle so it can detect another vehicle or a zoning system is used. Within a zoning system one vehicle is responsible for a specific zone this reduces the chance of collisions (Wan et al., 2011). With the use of AGVs the following issues arise: the AGV fleet size, unloading policies and the routing strategies. Determining the number of AGVs can have a big influence on the performance of the system. The goal is to achieve a stable state by setting the fleet size to an optimal number. The system is stable if the number of waiting goods stays at a stable level. The routing strategies focus on reducing the distance travelled (Ribino et al., 2018).

Navigation of AGVs can be established by a physical guideline, magnetic anchoring points, laser navigation or satellite navigation. Both the physical guideline and the magnetic anchoring points require adjustments to the floor, a line has to be painted on the floor or magnets have to be attached. These two navigation methods can be applied when the layout of the warehouse is simple without many junctions. Laser guided vehicles (LGVs) can be easily adopted in complex warehouses. With the placement of mirrors at strategic points the location of the vehicle is determined. The routing and dispatching is done with the use of a computer system. Advantages of LGVs are the high flexibility and a short pay-back period. Drawbacks of LGVs are that they can only move on predefined paths and congestion can occur on these paths (Ferrara, Gebennini, & Grassi, 2014). An important aspect is that markers should be recognizable and their positions should be fixed. The system is also able to recognize stable obstacles. Another method works with GPS positioning, the vehicle should always have a clear line of sight to the satellite. Due to this fact an indoor GPS needs to be installed within buildings. A high positioning accuracy can only be established with considerable technical effort (Ullrich, 2015).

Besides choosing the guiding of the AGVs there are also different vehicle type of AGVs for example: automated forklifts, automated guided carts, tugger AGVs and unit load AGVs. Automated forklifts are able to move goods vertically and horizontally. There are also automated EPTs these are able to move pallets horizontally by themselves. This means that they are able to pick up the pallet and drop it off. However, they are not able to lift the pallet up to a specific height. Automated guided carts are made to move carts or goods however they are not able to unload or load by themselves. The goods have to be put on top of the cart and taken off. Tugger AGVs can be compared with a small train the autonomous vehicle tugs a number of containers. The tugger AGV is not able to hook or unhook these container by itself. Unit load AGVs are mainly used to transport goods from a conveyor to another conveyor. They are able to handle many different type of goods, not only pallets. The unit load AGVs are also suited for handling heavy weight goods. The vehicles mentioned above drive on tires over a floor (Network, 27-3-2020).

A new development within automated vehicles are autonomous vehicles. AGVs have to follow predefined paths often indicated by magnets and lines. Autonomous vehicles do not longer need these kinds of predefined paths and are able to navigate dynamically based on a map. These vehicles have many sensors that can identify obstacles such as, people and cars, and avoid them. Since there is no fixed infrastructure required this reduces the costs (Fetch Robotics, 2018).

Besides vehicles that drive on floor level there is also another option, namely rail guided vehicles (RGVs). RGVs travel over a closed-loop rail path and are mostly used to connect two parts of a warehouse to each other. The difference between RGVs and conveyors are the throughput. For RGVs the throughput is dependent on the number of vehicles on the rail whereas on a conveyor the throughput is stable at any moment. The chance of congestion, with the use of RGVs, increases when more stops are added on the track and more vehicles than necessary are used (Martina, Alessandro, & Fabio, 2018). Moving speeds differ per vehicle type RGV are able to achieve higher speeds up to 4.4 m/s and a standard AGV up to 2.0 m/s (User, n.d.) The vehicle attached to the rail can differ per system and which vehicle is chosen depends on the goods that have to be transferred. Vehicles attached to the rail can be pallet size or car size.

The infrastructure during convention centers differs for every convention therefore it is hard to implement automated vehicles within halls. During the build-up and break-down of a convention the halls are very crowded and chaotic. Many construction workers walk through the halls to construct or demolish stands. Besides construction workers, another problem it that goods are stored on paths which blocks them. This makes the implementation of automated vehicles even harder since their movements are blocked by objects. However, if a convention center has a part within the logistics system that is more stable, implementing automated vehicles could be an option. Implementation of these vehicles could lower labour costs and improve throughput.

2.6 Conveyors

Conveyor belts are used to transport goods over a certain distance without human intervention. Where AGVs are flexible in moving around a conveyor belt is a fixed part of the infrastructure. Implementing conveyor belts can increase the throughput and efficiency of the warehouse. It can also reduce labour costs since no human intervention is required for the transportation of the goods on the conveyor belt (Ashrafian et al., 2019).

There are many different types of conveyors and choosing the right one is important. This decision is mostly depending on the goods that need to be transported. One of the most commonly used conveyors is the belt conveyor. This is one of the simplest conveyors, goods are placed on a belt which moves. Belt conveyors are mainly used to transport simple products. It allows for a continuous or indexing transport, indexing means that the belt stops each time a product is and the end of the belt. Conveyor belt types differ on the material used for the belt, width, speed and incline (Ultimation, 2019).

A type of conveyor that is focused on transporting heavy items is a chain conveyor. Instead of a belt it uses chains to transport goods. These conveyors are often used to transport pallets and containers. Products can also be fixed on a fixture, which can be placed on the chain conveyor. Since these conveyors are focused on transporting heavier goods the speeds are mostly lower than the speeds from other conveyor belt types. A chain conveyor can also offer continuous speeds or indexing. In Figure 2.2 the two types are shown (Ultimation, 2019).

Besides these two types of conveyors, more conveyor types exists different characteristics. However, these two type of conveyors seem most applicable to a convention center since they are able to transfer different type of goods. A convention center handles all type of goods and not only pallets. Therefore the conveyor should be able to handle these. Both the belt conveyor and the chain conveyor seem able to handle different type of goods. If the convention center handles a lot of heavy materials a chain conveyor would be a better option. The implementation of conveyors asks for a fixed infrastructure. The conveyors need to be build and cannot be moved afterwards. They take up space where normally EPTs or forklifts would drive. This could reduce the flexibility of the logistics since only the conveyor could be used for transportation. In case of a disruption all logistic processes would suffer from this.

(a) Belt conveyor

(b) Chain conveyor

Figure 2.2: Conveyor types

2.7 Cross-Docking

Cross-docking is a concept in which the loads of incoming trucks are sorted and immediately loaded in outgoing trucks. With the use of cross-docking less warehouse and storage space is required since goods directly move to the next vehicle for transportation, without storing them. Besides reducing the storage space it also reduces inventory management costs and turnaround times. To be able to implement cross-docking a good computer application is essential since much information is needed such as the final location of goods, which vehicle contains which load and the final location of vehicles. Another important aspect is the operational management of the cross-docking system. This operational management includes the synchronization of incoming and outgoing vehicles. To achieve this the schedules of the vehicles should be known on forehand (Yu & Egbelu, 2008). The efficiency of a cross-docking platform depends highly on the product flow. Three factors influence this flow namely travel distance between inbound and outbound doors, congestion and the moving path. The efficiency can be measured as the ratio of direct transited products to the total number of total transited products. Sequencing incoming and outgoing vehicles can increase the efficiency of the cross-docking platform (Maknoon & Baptiste, 2009).

The performance of cross-docking operations can be measured by different indicators. One of these possible indicators is the inventory level. A lower inventory level suggests a high performance of the system. Another indicator is the stay time, the goal is to keep products as short as possible in the system. Other examples of indicators are working hours, congestion, travel distance and loading/unloading time. Besides the factors mentioned before the layout of the cross-dock has an influence on the performance as well. There are different shapes a cross-dock can have. However, the most used cross-dock shape is an I-shape. This I-shape seems to be the most efficient since the travel distances from truck to door are relatively small (Ladier & Alpan, 2016).

Standard cross-docking means transferring goods from inbound trucks to outbound trucks. At convention centers this is not the case since the goods arrive with a truck and need to be transported to the hall with different vehicles, or the other way around. Forklifts and EPTs are the vehicles that are often used for transportation to the hall. An implementation of cross-docking at a convention center is shown in Figure 2.3. The goods are unloaded on the cross-dock and are then picked up by forklifts or EPTs to bring them to the hall. Implementing cross-docking can decrease unloading times of trucks and trailers at convention centers. A faster unloading process reduces the chance of queuing and can reduce the amount of logistic space required.

Another benefit of implementing cross-docking is that it makes the unloading process also easier to oversee. The drivers of the forklifts only have to focus on unloading the truck or trailer and there is no confusion about the destination of the pallet. In the current situation at the RAI drivers of forklifts have to search for the location within the hall or take the wrong routes. When there are dedicated drivers for forklifts and EPTs they can focus on their part in the process. An EPT is also easier to handle and takes up less space within the hall than a forklift. This can increase the moving speed within the hall.

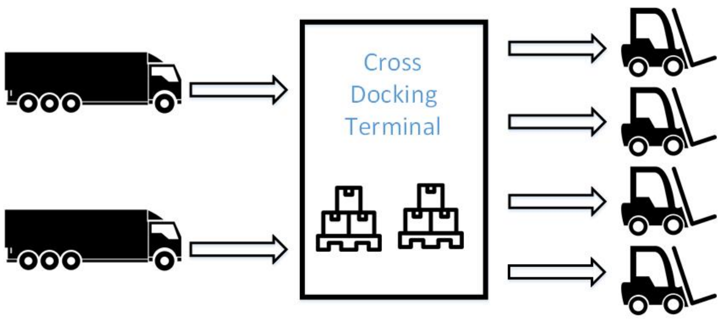


Figure 2.3: cross-docking

2.8 Underground logistics

Convention centers are often located within urban areas, due to this fact space is limited at most convention centers. The goal of convention centers is to sell as much hall space as possible. If logistic space can be reduced even more commercial hall space can be established. One way of reducing the amount of logistic space at ground level is the use of underground logistics. Underground logistics can consists of different aspects such as tunnels, underground logistic centers and underground storage.

Within cities there is a development towards Underground Logistics Systems (ULS). These systems ensure transportation within and between cities with the use of underground pipes or tunnels. ULS reduce traffic pressure at the ground level and are more reliable since there are less external conditions of influence. A downside of underground logistics are the costs, tunnels are expensive to construct compared to ground level infrastructure. Most ULS need location optimization to find out in which places these centers should be constructed (Ren, Fan, Wu, Zhou, & Du, 2019).

When building a tunnel different aspects have to be taken into account. The diameter of the tunnel has influence on the investment costs, the larger the tunnel the higher the costs. The diameter is depending on the required transport capacity and the vehicles or objects travelling through the tunnel. A decision can be made between an automated or a non-automated system. This means that the tunnel is open for vehicles such as trucks driven by truck drivers or has an automated system operates within the tunnel such as conveyor belts, automated vehicles or rail guided vehicles (Arends & de Boer, 2001).

At a convention center underground logistics can be interesting for transportation on the terrain and for transportation from a warehouse to the convention center. For the RAI the most important connection is the connection between the north and south complex. A tunnel could reduce traffic on the north side, which would reduce congestion and nuisance in the neighbourhood.

2.9 Methodologies

To study the redesign of the logistic network several methods and concepts are used. The following concepts will be discussed: queuing theory, conceptual model IDEF-0, requirement analysis, modelling and simulation method and multi criteria decision analysis.

2.9.1 Queuing Theory

Queuing theory describes the process of queuing, why it occurs and how it evolves over time. Queues are common in many industries such as supermarkets, banks and logistics. Within logistics queues can originate on different aspects. Queues can for example occur in front of a traffic light, on roads resulting in congestion and vehicles waiting for loading and unloading. A queuing system has an arrival process which described how customers arrive, based on the distribution of the inter arrival times. The goal of queuing research is to determine the main performance of the system. This performance depends on the number of customers and waiting customers in the system, utilization and serving times of the servers(Sztrik, 2016).

Within a queuing system the units waiting in the queue are called entities. These entities can represent customers, pallets, vehicles or any other object. The entities are waiting to be served by a server. A queuing system can consist of one or multiple servers. After serving the entities move on to the next server, leave the system or remain within the system. If the entities leave the system after being served it is called an open system, and otherwise a close system. A queue arises when the servers are occupied and the entity is not able to enter the server. As soon as the sever is available an entity within the queue is picked to be served next. Deciding which entity is next is described within the queuing discipline. Examples of queuing disciplines are first-in, first-out also called FIFO or last-in, first-out LIFO. Other disciplines are picking the entity on priority. To be able to determine the performance of a queuing system several performance measures exists. These are time in queue, time in system, number in queue, the number in system and the utilization of servers (Kelton, Smith, & Sturrock, 2014).

Since queues and long waiting times are undesirable much research tries to find methods, which reduce queues and waiting times. Within the literature several methods have been found. Queues originate when entities have to wait for an available server. The number of entities that can be handled by the servers within a given time frame is called the capacity. If the capacity is increased more entities can be served within the given time frame. To increase capacity the number of servers can be increased or the server time can be reduced. To determine to what extent servers should be adjusted simulation, statistical analysis or lean tools can be used. The adjustment in servers should be cost-effective. Increasing the number of servers results mostly in higher costs. Besides expanding the capacity there are also other methods to control queues. These methods focus on controlling the arrival processes of the entities that queue. A research on queuing in port terminals showed that queues can be reduced with the use of a toll system (Shahpanah, Shariatmadari, Chegeni, Gholamkhasi, & Shahpanah, 2014). A toll system is a kind of truck appointment system where the arrival patterns of arriving trucks and trailers is controlled. Trucks and trailers are forced within a dedicated time-slot. This ensures that the trucks and trailers arrivals are spread out over the day instead of them arriving at the same moment. If trucks and trailers would arrive at the same moment the amount of arrival vehicles can exceed the available capacity, which results in queues and waiting times. The toll system ensures a more stable arrival pattern of trucks and trailers without increasing the capacity at the port. Other methods to reduce queues are improving service efficiency and setting proper queuing disciplines. Increasing service efficiency can reduce the time the servers needs to serve the entity. If this time in reduced the server can handle more entities within a given time frame, which increases the capacity. Changes can be made to the server (L. Y. Wang & Feng, 2013).

Within queuing theory three main model types are used. They can either be deterministic, probabilistic or a mixed model. Within a deterministic model the arrival and service rates are known and within a probabilistic model they are unknown and distributions are used. The final option is a mixed model where one of the two rates is known and the other one is unknown. Besides the arrival and service rates a queuing model consists of one or multiple servers. If a queuing model exists of multiple servers they are often parallel used and the service are identical. The most basic queuing system exists of a Poisson distributed arrival process, an exponential distributed service process and has 1 server. The performance of these kind of queuing systems are easy to solve with the formulas of queuing theory. The more servers are included and when other distribution or real-world data is used it is difficult to solve these queuing problems with formulas (Kelton et al., 2014).

Another characteristic of queuing theory is that it tries to capture the steady-state of a system, this can also be explained as the long term behaviour of a system. This is done with the use of formulas and the average values of a system are used to calculate the performance. However, if the short-term performance of a system is of interest these formulas are not able to capture the short-term behaviour of the system. When the short-term behaviour of a complex system is researched it is recommended to use simulation instead. Simulation can also include real-data instead of an assumed arrival distribution. This makes it easier to represent the real-world behaviour. The outcomes of simulation models are expected to have a higher chance of being more realistic and valid (Kelton et al., 2014)

The freight logistic processes at the RAI can be seen as multiple queuing systems. The entities queuing are either trucks and trailers or pallets that need to be delivered. The first queue emerges when trucks and trailers are signing in at the RAI. They have to sign in at the gate, which takes several minutes. In this case the trucks and trailers are the entities and the gate can be seen as the server. This is a one server queuing system. As soon as the trucks and trailers are registered they are allowed to enter the terrain and drive to the area they need to be. To unload trucks and trailers need an unloading spot. If a spot is available the unloading can start immediately. However, it can happen that all available spots are taken. In this case the trucks or trailers has to wait for an available spot, which can results in a queue. In this case the trucks and trailers queue for the unloading spot, which can be seen as the server. The RAI has multiple unloading spots, which makes this a multi-server queuing system. As soon as the trucks or trailers start unloading the pallets wait to be transported. In this case the forklifts can be seen as the servers and the pallets as entities. The pallet is transported by the forklift and as soon as the pallet is dropped the forklift is going to pick-up the next pallet. Multiple forklifts are used which indicates that this is a multi-server queuing system. The arrival of trucks and trailers will be based on real-world data and not on a distribution. To determine the distribution of the service times data has to be obtained. The queuing models at the RAI can be described as mixed models since certain inputs are based on distributions and other on real-world data. The behaviour of interest at the RAI is short-term. This is the case since the logistics at the RAI differ a lot per day. Studying long-term behaviour will not show the problems on busy days, it will only show the average. If only the average is taken into account the RAI could face massive problems during busier days.

2.9.2 Conceptual Model

A conceptual model helps with translating the problem situation to what should be modelled and how this can be modelled. This process is iterative and repetitive, the model is a simplification a real world system. There are multiple reasons why a conceptual model should be made before simulating the system. For instance it helps with the communication between all parties involved. The conceptual model shows what is modeled and makes it easier to understand for outsiders (Robinson, 2011). There are many conceptual modelling techniques for example UML and IDEF-0. UML focuses on the objects in the system and IDEF-0 on the processes (Verbraeck, 2019).

Conceptual models are especially useful for simulation studies. Including a conceptual model early on can increase the quality of the simulation model and decrease the required time to build it. In this early phase the conceptual model is used to gather knowledge of the system. An often used conceptual model for simulation models is an IDEF-0. An IDEF-0 includes text and graphic elements that are represented in a systematic way in order to obtain understanding of the system. To capture all details of a system an IDEF-0 consists of hierarchical series of diagrams that increase in detail. The following four elements are used in the IDEF-0 inputs, outputs, mechanisms and control 2.4. Inputs are data or objects that are transformed in the process to outputs. Mechanisms are the means that are required to execute the process. Controls are the required conditions to obtain the right output (Montevechi et al., 2008).

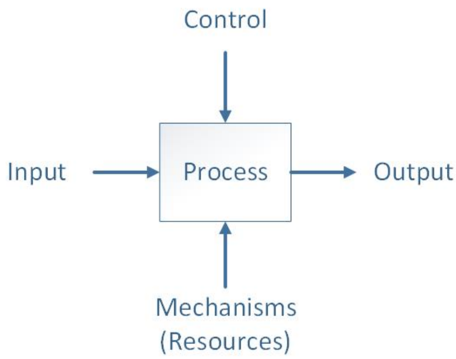


Figure 2.4: IDEF-0

2.9.3 Measuring System Performance

To measure the performance of a system, the efficiency and the effectiveness of it should be quantified. This quantification can be done with the use of key performance indicators (KPIs). With the use of KPIs it is possible to compare the past performance with the previous or current performances. Besides evaluating the current or previous performance KPIs can be useful to determine the future performance of a system (Krauth, Moonen, Popova, & Schut, 2005). Besides evaluating performance, KPIs are also used for decision-making. To evaluate the total performance of a system both financial and non-financial aspects should be taken into account. However, including too many indicators should be avoided. A decision has to be made on which indicators are most important for the system (Kucukaltan, Irani, & Aktas, 2016). Examples of KPIs in the transportation industry are revenue and on-time pickups. For every system the KPIs differ and a decision has to be made on which KPIs are included and why they are of importance.

2.9.4 Requirement Analysis

Requirement analysis (RA) is an element of requirement engineering (RE). If a new system fails the underlying problem is often that the requirements and specifications are not met. RE tries to overcome these problems by gathering, analysing, specifying and validating the user requirements. The goal of the RA is to alter found needs and requirements into consistent and complete requirements. When designing a new system RA is an essential step (Sharma & Pandey, 2018).

To identify requirements multiple tools and techniques can be used. One of the most used methods is stakeholder interviews. Interviewing stakeholders gives insight in how the current processes work and how the future processes should work. Each stakeholder has its own opinion on this point. These opinions give insights in potential barriers within the process. A disadvantage of interviews is that not all stakeholders are aware of what they exactly want, or it is difficult for them to explain. Another method is requirement specification this method gives insight in the desired actions of the system. Two types of requirements are distinguished non-functional and functional requirements. Functional requirements explain what the system needs to be able to do and non-functional requirements can be used to judge the process (Sharma & Pandey, 2018). Besides requirements the constraints need to be determined. Constraints are factors that limit the system design such as environmental factors (Defense Acquisition University, 2001).

Most requirements are operational, these operational requirements try to define the basic needs of the system. The operational requirements should be able to answer the following questions: Where will the system be used? How will the system accomplish the objective? What are critical system parameters? How are the various system components used? How efficient or effective must the system be? How long will the system be in use? In which environments must the system be able to operate? In literature multiple types of requirements are distinguished besides the functional and non-functional requirements. The following requirement types are often used (Defense Acquisition University, 2001):

- Customer requirements define the expectations of the system with the operator as most important customer.
- Functional requirements are about the task that needs to be accomplished.
- Performance requirements are about the extent to which a mission needs to be executed.
- Derived requirements are implied from higher level requirements. For example if a train is designed and it needs to be fast a derived requirement can be that it has to be low weight.
- Allocated requirements are established by dividing a high-level requirement into multiple lower-level requirements.

Within this research a requirement analysis will be performed to identify the requirements for the new logistics system. These requirements are gathered with the use of interviews and requirement specification. Multiple stakeholders will be interviewed to establish a good overview of the different requirements. The interview method that is used is the semi-structured approach. A semi-structured interview allows for open ended questions, which gives more room for discussion with the stakeholders. Semi-structured interviews are well suited for the exploration of opinions of stakeholders, even when the topics are complex and sensitive. Complex topics require more information than can be obtained with a structured interview. Questions should remain the same in every interview to obtain results that are only different because of the stakeholders and not because of the formulation of the questions. However, not all stakeholders use the same vocabulary so the meaning of the question should remain the same and the formulation could be different (Barriball & While, 1994). The obtained requirements will be used in the design phase of the new logistics system.

2.9.5 Modelling Techniques and Simulation

There are several ways to study systems and how the performance is influenced by certain changes. The easiest way to do this is to alter the actual system and see how it performs under alterations. However, changing the actual system is rarely possible since this is too costly and alterations might cause unwanted disruptions within the system. To be able to study the system without altering the actual system a model can be made. A model can be either physical or mathematical. Physical models are less suitable for research to systems, therefore mathematical models are mostly used. A mathematical model represents the system in terms of logical and quantitative relationships that can be manipulated and changed to see how the model would react. The reaction of the mathematical model is assumed to be similar to the reaction of the system if the model is validated. If the system is not too complex the mathematical model can be solved with the use of an analytical solution. However, when a system is highly complex a valid mathematical model is also highly complex and hard to solve with an analytical solution. Instead of an analytical solution the model can be studied with the use of simulation (Law & Kelton, 1991). Analytical solutions can predict the system behaviour and are less expensive than developing a simulation model. However, with the use of a simulation model the system behaviour can be simulated and estimations based on the system behaviour can be made such as performance. Simulation models are better in capturing highly detailed system behaviour compared to analytical models (Gokhale & Trivedi, 1998). Due to this fact simulation seems to be more suitable for the simulation of the logistics system of a convention center.

Simulation

Different simulation techniques exists with different characteristics and purposes. Choosing the simulation method is depending on the system that is being simulated and which information needs to be obtained from the simulation model. When choosing a simulation method it is important to understand certain characteristics of the system. A system can be static or dynamic, deterministic or stochastic and continuous or discrete. A static system is a representation of a system where time plays no role, in a dynamic system time does play a big role. Deterministic systems do not contain any probabilistic components thus has no randomness, a stochastic system does include randomness (Law & Kelton, 1991). A discrete system means that the variables within the system change in discrete times by discrete steps, continuous simulation is used when variables can change continuously (Özgün & Barlas, 2009). For example a discrete process are the arrivals of persons at a post office, and a continuous process is the water flowing out of a tank. For continuous systems a suitable simulation methods is system dynamics, and for most discrete systems discrete event simulation (DES) is used (Özgün & Barlas, 2009). Another important simulation technique is agent based simulation. An agent based simulation consists of autonomous agents that make decisions and interact with each other and its surroundings. It simulates a system on a microscopic level and is therefore able to model certain aspects of an agent (Abar, Theodoropoulos, Lemarinier, & O'Hare, 2017). A main advantage of agent based modelling compared to other methods is that decisions can be made automatically based on experience. (Maka, Cupek, & Wierzchanowski, 2011). Agent based modelling is used in logistics and in warehouse operations and a combination with DES can be made, this ensures the possibility of adding intelligence to certain entities. DES is process oriented and most entities in the system are passive. Including agent based modelling can make these entities more active and the system obtains a more task driven view (Pawlewski, 2015).

The logistic network of the RAI can be described as a dynamic, stochastic discrete system. The system state changes over time by the occurrence of an event for example the arrival of a truck. Therefore discrete event simulation is more suitable than a continuous approach such as system dynamics. Most processes within the RAI are straight forward and do not consists of many decisions. Therefore a DES simulation model will be used.

Discrete Event Simulation

DES models are developed to mimic the behaviour of a system and it keeps track of the performance and the conditions the system is in. The performance and the conditions of a system at a given time is called a state. These states can only change instantaneously by the occurrence of an event (Jacob, 2013). DES models are mostly used for modelling system performance, inventory planning/management and production planning & scheduling (Tako & Robinson, 2012). A DES model can show a high level of detail and the models are mostly used on operational and tactical level (Rabe, Klueter, & Wuttke, 2018). DES is also an useful tool to identify bottlenecks in systems (Nilsson, 2001). These characteristics makes DES a very suitable method for the simulation of logistics systems. Especially when multiple designs and scenarios are tested and compared. In the past DES has been used to explore the possibilities for consolidation centers (Rabe et al., 2018) and for the logistic network in container terminals (Roeder, 2016) and many other subjects in the logistic field.

Besides these advantages of using DES there are also some disadvantages. The more complexity is added to the model the harder it is to understand. The transparency of the model reduces when complexity increases making the functioning of the model hard to understand for outsiders. Besides reducing transparency, running times will increase with the increase of complexity. DES also requires much data and when data is missing assumptions have to made making it hard to determine if the model is accurate (Caro & Möller, 2016). Another disadvantage is that entities move on predefined path and routes. Entities move from point to point and have no choice on the route they take these choices on routing of entities are hard to include (Dubiel & Tsimhoni, 2005).

2.9.6 Multi Criteria Decision Analysis

Decisions within the transport and logistic field involve multiple actors and are often complex. Most of the time multiple alternative solutions exist for a problem. However, choosing between these alternatives is difficult. For these complex decision situations tools such as multi criteria decision analysis (MCDA) can be used. MCDA makes it possible to evaluate several alternatives on quantitative and qualitative criteria. Within MCDA several techniques exist depending on the problem situation a technique should be chosen. The goal of a MCDA is providing a ranking of the possible alternatives from most wanted to least wanted. This ranking is obtained by scoring the alternatives on different criteria and assigning weights to these criteria (Communities and local governments, 2009) A MCDA technique that is often used in the transportation field and other fields is the analytical hierarchy process (AHP) (Macharis & Bernardini, 2015).

AHP sorts the factors that have influence on the decision process in a hierarchical order. It starts with the goal of the decision followed by the criteria and the set of alternatives that can be chosen. To assign weights to the criteria pairwise comparison is used. This means that the importance of the criteria is established by comparing all criteria with each other. The advantage of using pairwise comparison is that it results in only a small inconsistency within the choices. This inconsistency increases when the problem owner is asked directly to assign a weight to a criteria instead of using pairwise comparison (Saaty, 1990).

In this research multiple alternatives will be designed to improve the logistics system. Each alternative scores different on the KPIs/criteria. These KPIs and criteria are of different importance to different stakeholders. To determine the importance of the KPIs weights can be assigned with the use of AHP. AHP has proven to be a reliable method for determining criteria weights and makes it easier to see the trade off between different alternatives. Therefore, this method will be used on the alternatives results obtained from the simulation.

2.10 Conclusion

To answer sub-question 1: *"Which logistic problems are convention centers facing"* literature on convention centers is studied and the situation of the RAI is explored. One of the most important problems is the location of convention centers. Most convention centers want to be located near cities since these offer interesting facilities. Over the years more attention is raised for the environment within cities, which results in stricter rules and regulations for convention centers. Municipalities of cities implement new regulations to reduce negative external effects for residents and the logistics of convention centers is affected by these regulations. Convention centers are forced to reduce negative external effects such as air pollution and noise pollution. Another downside of a city location is the lack of space. Most cities are crowded and every meter of space is used. Therefore it is almost impossible to expand the terrain of the convention center. H

Besides meeting regulations conventions are time-critical. A convention has a tight schedule, there are only a few days for the build-up of the convention and only a few break-down days. Within these days all vehicles and materials have to be handled and delivered to the right location at the right time. This means that the logistics has to handle high peaks of trucks and trailers. Logistics at convention centers should be able to deliver everything on time to make sure the build-up and break-down of the convention is finished within the given time. The logistics should also be flexible since every convention is different. The logistics should be able to adjust to these different conventions.

Good communication between the convention center and the involved parties is important. If communication is poor trucks and trailers show up when they are not supposed to leading to chaotic situations. A good communication and a share of information should be established to improve the logistic process.

Convention centers sell space and the more space they can sell the more profit they make. Besides the profit a large amount of commercial space also ensures a competitive position compared to other convention centers. Reducing the amount of logistic space can increase the amount of commercial space, which is interesting for convention centers.

The main problems are therefore the lack of space, time-critical events, flexibility, communication and governmental regulations.

To answer sub-question 2: *"Which technologies and strategies can be used to improve logistic performance at convention centers or similar industries?"* literature on convention centers and other industries is explored.

Within the literature on convention center logistics possible solutions are mentioned for improvement. These methods are the implementation of IT systems and outsourcing of logistic processes to private companies. Since literature on convention center logistics was lacking several other industries are studied. Within other industries the following technologies and strategies came forward as useful for convention center logistics: truck appointment system, automated guided vehicles (AGVs), conveyors, cross-docking, underground logistics and IT systems. How these technologies can be used to improve convention center logistics is explained shortly.

With the use of a truck appointment system vehicles subscribe to a certain time-slot, this reduces congestion and waiting times. The use of AGVs can automate the delivery of goods from trucks to halls, this reduces labour costs and human errors and increase productivity and consistency. Implementing AGVs is challenging since they need severe infrastructure adjustments to operate. Another option to automate transportation is the use of conveyors. Implementing conveyors can increase efficiency and throughput. However, implementing conveyors asks for a fixed infrastructure, which decreases the flexibility. The strategy of cross-docking can reduce storage space and costs. Vehicles are unloaded with the help of forklifts and the goods are stored in the cross-docking area. Other vehicles pick up the goods from this area and transport them to the final location. Underground logistics decreases nuisance of logistics to the environment, transportation is also faster since there are no disturbances. However the construction of underground logistics is complex and has high costs. And finally IT systems are needed to support technologies and strategies. Most of the strategies and technologies above need IT systems to operate such as RFID. With the help of IT systems the share of information becomes easier. Information such as location of vehicles and loads are easier to obtain. With these kind of information planning can be more efficient and the efficiency of the system can increase. These IT systems require a good network of antennas, readers and a wireless LAN. A malfunction within this network has serious effects on the IT systems. The IT system can function incorrectly or can even be completely down. If the system is down logistic comes to a stop since the information needed for transportation is lacking. Having a reliable back-up systems prevents such major problems.

Part II

Measure

3 | Current Logistics

In this chapter the current logistic process will be explored and sub-question 3 will be answered (section 1.6). To study the logistics system the current logistic processes and the involved stakeholders are explored. To be able to examine the performance of the current system and the future system key performance indicators are introduced. The data needed to determine performance is discussed and useful insights obtained during the collection of data are given.

3.1 Logistic Process

In Figure 3.1 the lay-out of the RAI Amsterdam is shown. The terrain can be split into three parts the Holland complex, the congress centre and the Europe complex. The Holland complex is located on the south side and consists of exhibition halls 8 till 12. The Europe complex is located on the north side and consists of exhibition halls 1 till 7. Within this research there is often referred to the north or south side of the RAI. When the north side is used it refers to the Europe complex and the south side to the Holland complex. The congress centre consists of offices and smaller convention rooms. Within the exhibition halls stands are built during conventions, which require considerable materials and goods. The rooms within the congress center do not require many materials. Therefore the logistics to the Holland and Europe complex are very important. The RAI had dedicated work sites for freight logistics. On these work sites vehicles are able to unload goods and deliver them to the halls. In Figure 3.1 the work sites can be recognized by the blue colour. The Holland complex has two work sites which are called the P5A and P5B. The Europe complex has three work sites the P8, P9 and P10.

At these work sites vehicles are parked and unload the goods and transport them to the right hall. During the build-up and break-down of small conventions the work sites are open to all vehicles. These vehicles can be trucks, trailers, vans and personal cars. However, during large conventions the work sites are only available for trucks, trailers and large vans. Large conventions require more deliveries from trucks and trailers. If a work site is full arriving vehicles have to wait until an unloading spot becomes available. To reduce the chance of a full work site personal cars and vans are banned from the work sites. These vehicles have to park within the parking garages. These are shown in Figure 3.1 and can be recognized by the yellow colour. The RAI has four parking garages which can be used by personal cars and vans to unload goods. The P1, P2 and P3 can be used for vehicles up to 1.90 meters and the P4 can handle vehicles up to 2.70 meters. The rules regarding the availability of the work sites change for every convention. Therefore the RAI makes a document which describes the traffic regulations for the specific convention. It explains which type of vehicles are allowed on the work sites and during which times they are allowed to enter.

Within Figure 3.1 the flow of the goods are shown with the use of arrows. From the work sites the halls can be easily reached. However, the parking garages, used for unloading, are located on the south side. This means that the goods have to be transported from these parking garages all the way to the north side. The goods are transported via the logistic route through the inner area from the Holland Complex to the Europe complex. This inner area is used as a walking path during conventions and during build-up for transportation of goods.

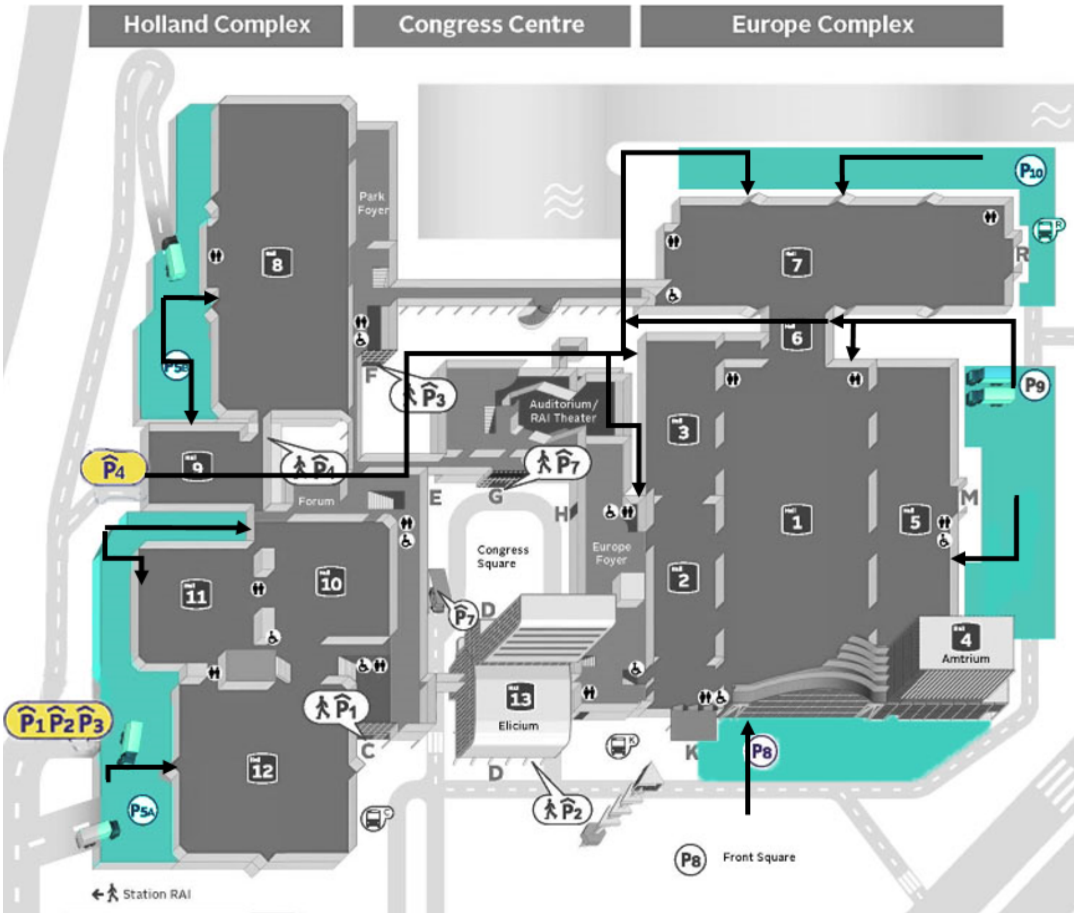


Figure 3.1: Flow of goods and vehicles in the RAI, green stands for loading and unloading zones, yellow for parking garages used for loading and unloading

During large conventions there are days where hundreds of trucks and trailers deliver goods to the RAI. The available logistic space at the RAI has proven to be insufficient for these amount of trucks and trailers. Therefore, a buffer area was introduced. This buffer area is located in Westpoort which is on the north-west side of Amsterdam. The distance to the RAI is 16 kilometers and the drive to the RAI takes around 20 minutes. During these busy days all trucks and trailers have to register at the buffer before they can enter the work sites at the RAI. Vans and personal cars can drive to the RAI immediately and use the parking garages for unloading. An exception is made for vans that have heavy loads. They are allowed to register at the buffer as well for a spot on the work sites. The vehicles are hold at the buffer until the RAI gives a signal of approval for the truck of trailer. The trucks and trailers are then allowed to drive to the RAI and enter the work site.

When the buffer is in use the RAI tries to inform all drivers in advance. However, it occurs that drivers are not aware of this. If trucks and trailers show up at the RAI without a registration form the buffer they are send back, which leads to chaotic situations and irritation. Therefore, the drivers are also informed on the highways with the use of DRIPS (Dynamical Route Information Panels). These Panels inform that the buffer is in use and which route the drivers should follow. The buffer can fit around 90 trucks and is 15.000 m^2 big (Swaak, 2018). The use of buffer location can improve the distribution of arriving freight traffic and decrease peak behaviour at the RAI (RAI Amsterdam, n.d.-a). This reduces the chance of queues at the RAI site. The queues are moved to the buffer area where space is available. However, it does not reduce the waiting times for the trucks and trailers. Instead of waiting at the RAI they have to wait at the buffer area. When less vehicles are expected the buffer is not used and vehicles are allowed to drive immediately to the RAI. An overview of the regulation at a busy day is given in Figure 3.2

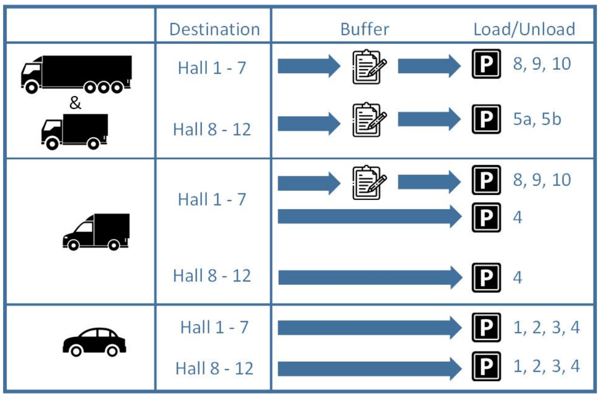


Figure 3.2: Current traffic plan during big conventions

The unloading process can be divided into five main parts. First, the truck or trailer arrives at the work site. Second, the truck or trailer is checked at the entrance of the work site if the check is positive the truck or trailer is allowed to enter the work site. Third, the trucks or trailer arrives at the unloading spot and parks. Fourth, the unloading starts, which means that the goods are taken out of the truck or trailer. Fifth the goods are transported to the right location within the hall. To be able to understand the details of the unloading process an IDEF-0 is made Figure 3.4. Within this figure there can be seen which inputs, outputs, control and mechanisms are used. It also gives an overview on all the sub-processes that find place for the total unloading process. The processes will be described shortly.

Trucks and trailers arriving at the RAI drive to the work site, which is located near the hall they need to deliver to. The RAI has multiple work sites and logistic staff helps to send drivers to the right working terrace. According to the traffic regulations certain trucks and trailers are allowed on the unloading area.

After the arrival at the work site the logistic staff checks the trucks and trailers and registers them. They check if the trucks and trailers are at the right work site and if they are allowed on it at this certain time point. If the check is positive the truck or trailer is allowed to enter the work site. The licence plate, location and arrival time is noted for every truck or trailer.

After the check the truck or trailer is directed to a unloading spot, the logistic staff is in charge of this. When placing the vehicles on a spot traffic and unloading regulations have to be taken into account to ensure safety and efficiency.

Once the truck or trailer is placed at the unloading spot the unloading can start. The unloading of trucks and trailers can be done in two ways. Either the drivers do it by themselves or the logistical partner of the RAI is used. The logistical partner is the only company that is allowed to operate motorised vehicles for unloading. This means that the self-loader has to unload the vehicle by hand, this is done with the use of pallet jacks. When the truck or trailer makes use of the logistic partner the unloading and loading process is done with the use of forklifts and EPTs. In Figure 3.3 the available loading and unloading vehicles are shown (Jungheinrich, 2019). The current rules at the RAI state a maximum loading and unloading time. Trucks longer than 12 meter get one hour, trucks longer than 8 meter get 45 minutes and smaller vehicles 30 minutes. However, in practice many vehicles exceed this maximum unloading times often. The main influence on the unloading times is the amount of goods that the vehicle is delivering. A logical assumption would be that larger vehicles deliver more goods than smaller vehicles, and get more unloading time. However in practice it occurs that large trailers only deliver one or two pallets.

Once the goods are unloaded they have to be transported to the hall. This transportation is done with the same vehicles used for unloading. This means that forklifts and EPTs are used to transport the goods for the logistic partner users and pallet jacks are used by the self-loaders. Within the hall transportation is done via two type of paths normal paths and yellow paths. Yellow paths should be free of obstacles at all times for a better transportation flow and for safety precautions. Normal paths are often blocked by obstacles since these paths are used to store building materials during the construction of the stand. Manoeuvring over these paths with vehicles is challenging especially with forklifts since space is limited.

(a) Forklift

(b) Drivable EPT

(c) Electric pallet jack (hand EPT)

(d) Pallet jack

Figure 3.3: Unloading and loading vehicles

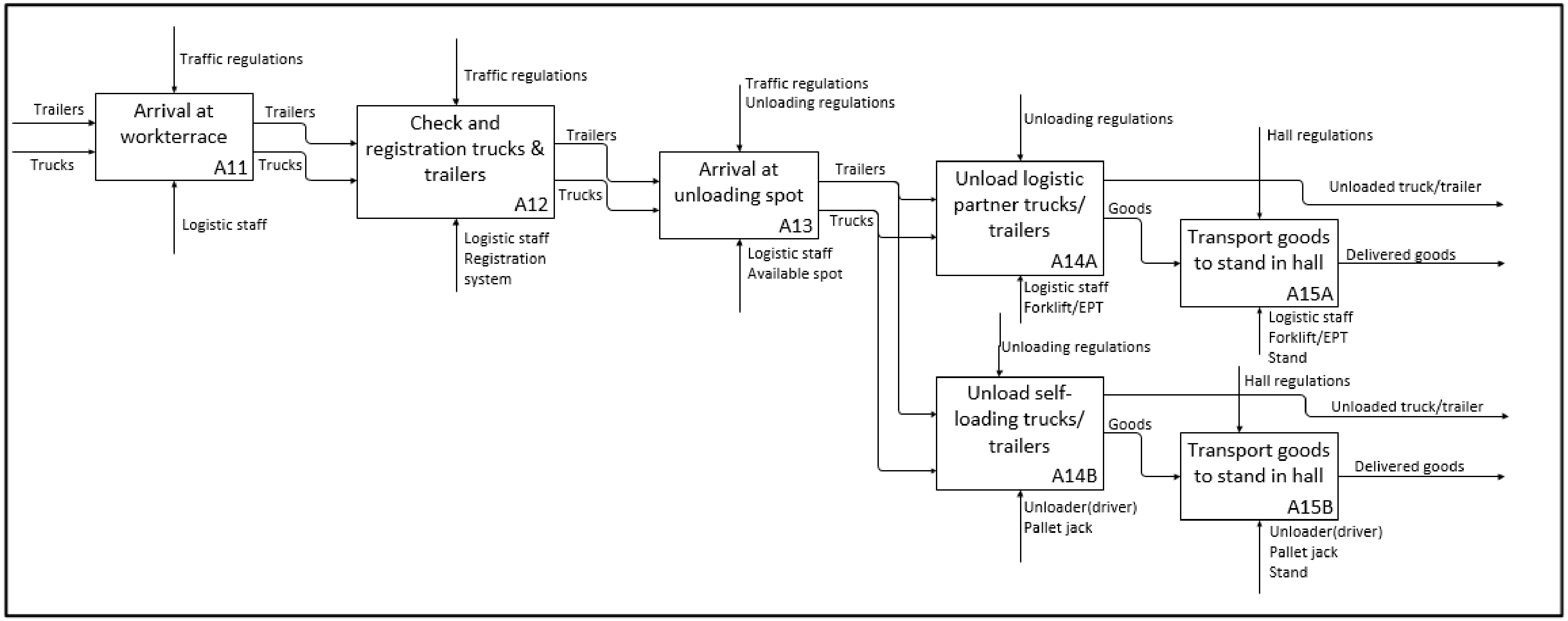


Figure 3.4: IDEF-0 unloading process

3.2 Stakeholders

Organising the logistics for a convention or event involves multiple stakeholders. To understand how the stakeholders within the current system function it is important to know which actors are of importance, how they relate to each other and what their responsibilities are. An overview of the important stakeholders of the RAI and their relations can be found in Figure 3.5[1]

The RAI consists of different departments. Two of these departments are clients and operations, both departments have several sub departments. The sub departments of importance are event management, traffic management and planning & support. These three departments are involved in the logistics at the RAI. The departments have different responsibilities.

- **Event management:** is responsible for everything that is going on within the halls. They are responsible for materials, resources and services from the RAI and the logistic partner to exhibitors. This includes transportation of goods within the halls, control on stand configurations, safety within the hall, cleaning and monitoring of the build-up and break-down.
- **Traffic management:** is responsible for all logistics around the RAI until the goods go into the halls, within the hall responsibility shifts to event management. They operate the buffer, work sites, parking garages, taxi stands and rental bicycles.
- **Planning & support:** is responsible for the master planning of a convention or event. This master planning includes which logistic suppliers and deliverers are allowed to deliver certain goods at a certain time.

Within the RAI it is often unclear who has responsibility for certain logistic processes. Good communication between the three departments is necessary to achieve efficient logistics. Much work is done to improve communication; however, further improvements can be made. For example: it happens that a stand builder is behind schedule and the next materials are already delivered. This means that the truck has to wait outside till the stand builder is ready or the goods have to be stored somewhere in the hall. These goods mostly end up next to the stand since this is convenient for the stand builder. When goods are stored close to the stand this creates inefficiencies since paths are blocked and less work space is available see Figure 3.6. It is unclear who is responsible for the coordination between these departments. At the moment the departments feel responsible for their own section within the logistics system and are focused on the execution of this specific part. This means that traffic is responsible for the transportation to the hall, however knowledge about the situation within the halls is lacking. The Traffic department is responsible for sending the trucks to the RAI and are not always aware on the fact that these trucks are not needed at this point in time.

As can be seen in Figure 3.5 the departments of the RAI interact with several other stakeholders. These stakeholders are exhibitors, external planners, logistic partners, external logistic companies and stand builders. The RAI works with two main logistic partners Ceva and Schenker, which logistic partner takes care of the event is depending on the event organisers. The chosen logistic partner is the only company that is allowed to operate forklifts and other motorised vehicles at the RAI site. This means that the logistic partner also has to cooperate with the external companies since they have to unload their trucks and trailers with their forklifts. Exhibitors are free to transport the materials of their stand with their own logistic company and work with their own stand builders. During large conventions many different companies are present. The RAI tries to inform these companies as much as possible on rules and regulations. However, this is a hard process since not all companies are known and many companies are from foreign countries, which results in a language barrier. In the last year the RAI has made several improvements to better the communication by introducing traffic regulations for exhibitors and deliverers. They made a website where all rules and regulations of specific conventions can be found. This makes it much easier to spread the rules and regulations between stakeholders and keep everyone updated. Several conventions worked with these online traffic regulations and it seemed to work quite well. In the future it is expected that all conventions will use these online traffic regulations and all involved parties are able to easily find and use them. The main planning is made by the RAI department planning & support; however, there are also external planners. Exhibitors can work with an external planner who arranges the delivery of materials, the build-up and break-down for them.

[1] Within figure "..." stands for other departments that are left out since they have no connection to the logistics

The relation between the RAI, the municipality and the residents living near the RAI is important and complex. The municipality of Amsterdam owns a quarter of the shares of the RAI and has a saying in the changes that are made within the RAI. The goal of the municipality is to keep residents satisfied and on the other hand keep the regional economy healthy (Amsterdam, 15-10-2019). International conventions at the RAI contribute to the regional economy (RAI Amsterdam, n.d.-a). However, the residents experience nuisance from the RAI due to the large number of vehicles driving through their neighbourhood and unloading close to their houses. The municipality tries to influence the RAI to limit the nuisance for the neighbourhood. The residents near the RAI can have different roles they can be a visitor, organiser or an employee of the RAI. Besides the nuisance to the residents the RAI also has positive influences on the neighbourhood such as employment opportunities and the organisation of events for the neighbourhood.

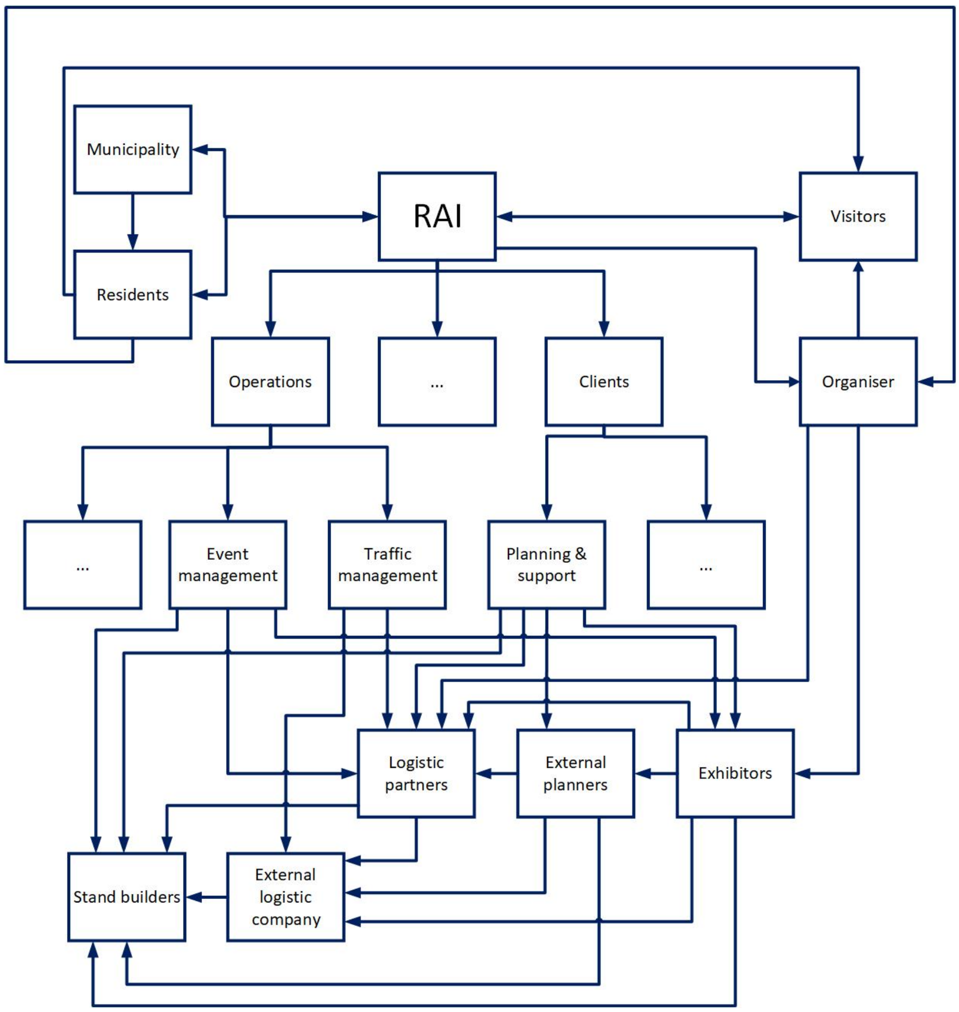


Figure 3.5: Stakeholder overview

The RAI has to cooperate with many different stakeholders. This means that if the RAI want to implement changes these stakeholders have to be informed and willing to cooperate. During interviews with the RAI (Appendix C) it came forward that certain stakeholders find it hard, or do not want to adjust to these changes. An example of this is the use of the buffer area in Westpoort. Certain convention organisers did not like the idea of a buffer and refused to work with it. However, the conventions that did use the buffer had a better organised build-up and break-down. Forcing convention organisers into changes that they do not like could result in a decrease in conventions since they choose another convention center to host their convention. The RAI has the difficult task to convince and show these stakeholders that their adjustments are necessary and improve their logistics. Besides convincing the convention organiser to adjust other stakeholders have to be convinced as well. For example: another idea for the future is to extend operational times to late in the evening. This gives more flexibility to stand builders and exhibitors to deliver their materials and build their stand. However, it is possible that employees such as stand builders, deliverers and traffic employees do not want to work at these hours. Longer hours can also increase costs for the logistic partner and the RAI. Within the neighbourhood extending operational time can increase the nuisance. If there are still trucks and trailers unloading late in the evening this could annoy residents. These examples show that making adjustments at the RAI is not an easy task. The opinion of all stakeholders need to be included to estimate the potential effect of such an adjustment. If this is not done an adjustment could lead to less conventions and thus income or more complaints from the neighbourhood.

3.3 Key Performance Indicators

Key performance indicators (KPIs) are used to measure the performance of systems. The following six KPIs are of importance to determine the system performance of the RAI logistics system. Within Appendix A the relationships between KPIs and other factors are shown with the use of a quantitative model.

- **Space [m^2]:** The total space required for logistics at the RAI site
- **Unloading time [minutes]:** The time it takes to unload a truck or trailer
- **Waiting time [minutes]:** The time a truck or trailer has to wait before getting assigned to an unloading spot
- **Delivery time [minutes]:** The time it takes to deliver goods to the final destination from the moment the goods are ready to be unloaded from the truck or trailer
- **Number of vehicles [number of forklifts and EPTs]:** The total number of vehicles (forklifts and EPTs) required for transportation and unloading of goods on the RAI site
- **Nuisance [number of trucks and trailers]:** The total number of truck or trailers that enter the working terraces at the north side of the RAI per day
- **Costs:** The estimated investment costs

Space

A convention center sells commercial space as its main income. Since the RAI is located in Amsterdam available space around the RAI is limited. Therefore horizontal expansion of the terrain is not possible. Much space around the RAI is occupied by logistics and during large conventions the available space is already insufficient. In the future the RAI wants to reduce the logistical space especially at the north side of the complex. To achieve this the logistical system needs severe changes to be able to handle the same amount of trucks and trailers without losing performance. The logistic space at the RAI site consists of the storage space and the space occupied by the logistic infrastructure. However, for simplicity this research will only include the space required for unloading spots and buffer or storage areas at the work sites. Changes that would reduce the storage and infrastructural space are desirable.

Unloading time

The unloading times of trucks and trailers is the time it takes to unload the truck or trailers completely. The time starts as soon as the truck or trailer is parked at the unloading spot and ends when the truck or trailer leaves the unloading spot. The unloading time is influenced by the amount of goods that have to be unloaded, the way unloading is done and side-activities of the driver. Unloading can be done either by hand (self-loaders) or with forklifts (logistic partner). If forklifts are immediately available to unload the truck or trailer the unloading time can be kept low. However, it happens that the forklifts are occupied with the unloading of other trucks and trailers. In this case the new truck or trailer has to wait for a free forklift. A low unloading time is preferred since loading spots are occupied less time and this increases the capacity the RAI has. This increase means that the spots can serve more truck or trailers if unloading times are kept low.

Waiting time

During busy days it happens that trucks or trailers have to wait for an unloading spot. This happens when all spots are occupied or not available. The waiting time is influenced by the number of arriving trucks and trailers, the number of unloading spots and the unloading time. The RAI has certain peak hours, within these hours most trucks and trailers arrive. These peak hours occur mostly in the morning. During these busy hours it occurs that the inflow is higher than the available capacity. The capacity can be increased or reduced by altering the number of available unloading spots and the unloading time. If the unloading times of trucks and trailers decrease a spot can handle more trucks and trailers within the same amount of time, this increases the capacity. A higher capacity means that more trucks and trailers can be handled and the chance of long waiting times reduces.

When trucks or trailers have to wait for a spot they from a queue. These queues take up space at the RAI site or on the public roads. This can cause unsafe situations and nuisance to the neighbourhood. Truck drivers are also unhappy with extensive waiting times. Therefore a logistics system without waiting times is desired.

Delivery time

Delivery time is defined as the time it takes to deliver goods at their final location after they are unloaded from the truck or trailer during the build-up. The delivery time starts as soon as the goods are ready for unloading. In other words the delivery time starts at the moment the truck or trailer opens the doors to start unloading. Since the goods are unloaded and delivered one at a time from the truck or trailer the first unloaded goods have a lower delivery time than the final unloaded goods. The delivery time can also be seen as the time the goods were in the logistics system.

The delivery time is influenced by the transportation time and the waiting time for transportation. The transportation time of the goods is influenced by the speed of the vehicle (forklift, EPT, hand) used for transportation. This vehicle speed is depending on the situation on the paths within and outside the hall. If paths are clear of obstacles a higher speed can be reached and the delivery time will reduce. Obstacles within halls exits due to human errors and early delivered goods. The paths are used as a storage space for the early delivered goods blocking the path for other vehicles, which reduces the overall speed of the delivery.

The waiting time for transportation is influenced by the number of available transportation vehicles and the transportation time. If there are more vehicles available more goods can be handled at the same time. If transportation times reduce the vehicle spends less time transporting the good and is faster available for the next delivery.

Number of vehicles

The number of vehicles is defined as the vehicles required for the transportation of goods at the RAI site. These vehicles can for example be forklifts, EPTs and pallet jacks. Goods are transported from the truck or trailer that is being unloaded to the final destination within the hall. Increasing the number of vehicles can reduce the total unloading time and the delivery time which increases the capacity, since waiting times will reduce. However, vehicles are costly and driven by humans, which increases the labour and material costs. Increasing the amount of vehicles can have a negative effect on the congestion within the halls as well. If more vehicles drive within the halls more crossings between vehicles happen, which can cause congestion. An alternative, which uses less vehicles with a high performance is preferred.

Nuisance

Nuisance is an indicator that is hard to measure; however, this is an important aspect for the RAI. There are many complaints from the neighbourhood about the traffic situation. The amount of trucks and trailers that drive through the residential area on the north side cause congestion and unsafe traffic situations. Another aspect is the noise that is made during the unloading of trucks and trailers on the work sites at the north side of the RAI. Nuisance will be defined as the amount of trucks and trailers that enter the work sites at the north side of the RAI per day. The more trucks and trailers enter this side the more nuisance there will be. An alternative, which reduces this as much as possible is preferred to keep the neighbourhood and municipality satisfied.

Costs

Finally system costs are important as well. A system with a high performance and relatively low costs is desired. However, it occurs that a system with a high performance leads to high costs. If costs are not included a good performing system can be seen as a good option. However, the costs could be so high that implementation of this system is not an realistic option. Therefore, it is important to include costs as a KPI.

The costs included in this research only cover the investment costs. These are the costs that have to be made to establish the designed system. These costs can for example be the costs to adjust the infrastructure and costs for developing and implementing IT systems. Operational costs are mainly depending on the amount of vehicles and since this is already a KPI the decision is made to not include the operational costs.

3.4 Data Collection

To be able to analyse the current system and determine its performance data is required. The required data is based on the KPIs that are used to measure the performance.

Currently the RAI has a total of 31.850m^2 logistic space (Buck Consultants, 2019). These numbers include the work sites, roads, buffer area and storage areas. Within this research the decision is made to mainly focus on the required space for unloading areas and buffer or storage space on the work sites. The size for an average trailer unloading spot are 4 meters wide and 19 meters long (van Berkel, 2020-02-29T13:28:27.000Z). The expectation is that two trucks fit on one trailer spot and therefore require half the size of a trailer unloading spot. Within the buffer or storage are on the work sites goods are stored. Goods are stored within the storage if it is not possible to transport them immediately into the hall. The space required for storage is determined by the number of pallets within the storage area. the size of a standard pallets are 0.8 meters wide and 1.2 meters long. The data to determine the required space are thus the amount of unloading spots and the amount of pallets within the storage or buffer area.

To measure the total unloading time of trucks and trailers it is necessary to obtain data about this process. The total unloading time can be determined by timing the arrival and departure of trucks and trailers. An important factor on the unloading time is the characteristics of the unloading process. The truck or trailer can be unloaded with the help of the logistic partner or by the driver itself (self-loader). This data is required since the unloading process differs for these two types. The unloading time is also influenced by the load of the truck or trailer. A small load will be unloaded faster than a large load.

To be able to determine the waiting times of trucks and trailers information should be obtained on the arrival process, the unloading times and the amount of unloading spots. Waiting times originate when the number of arriving trucks and trailers exceed the amount of available spots.

To determine the delivery time information is required about the speed and the distance that is covered for the delivery. The delivery is made from the truck or trailer to the final destination within the hall. With the average speeds of the vehicles (forklift and EPTs) the delivery time for each delivery can be determined based on the distance and the vehicle type used for the delivery.

The number of vehicles (forklifts and EPTs) required for transportation of goods on the RAI site in the current situation is a given; however, for future alternatives this is a variable. To determine the number of vehicles necessary certain data has to be collected. The vehicle speed is of importance and the total load they need to transport.

Nuisance is measured by the total number of trucks and trailers that arrive and unload at the north side. To determine this number information should be gathered on the arrival process and the destinations of the trucks and trailers.

3.4.1 Available Data

The RAI collects data from every convention, as mentioned before the data differs for every convention. For every convention they have details on the amount of vehicles arriving at a certain work site per hour. With this data the arrival patterns can be estimated. However, details on the vehicle characteristics and the exact arrival times are not noted. Besides the general data they have a more elaborate data set for one of their larger conventions, which is called the PLMA. The data set of this convention is used to determine the arrival patterns of the arriving vehicles. The data from the PLMA was retrieved in 2018 and all the vehicles arriving at the buffer and the work sites of the RAI are registered this includes trucks, trailers, vans and cars.

The following data is available in the data set.

- License plate of the vehicle
- Vehicle type (Trucks <8 meter, 8-12 meter and >12meter, vans, cars and cars with a trailer)
- Arrival date
- Arrival time at buffer
- Departure time at buffer
- Arrival time at RAI
- Departure time from RAI (only for a limited amount of trailers)
- Hall destination
- work site destination, north or south

Not all data in the data set is complete and there are multiple double arrivals of vehicles. It happens that a vehicle makes deliveries to the RAI multiple times a day. However, vehicles with the same license plate that arrive within 10 minutes after each other are removed from the data set. In a few cases the vehicle only has a departure time at the buffer and no arrival time. The arrival time at the RAI is calculated for these vehicles by adding up the average travel time, which is around 20 minutes, to the departure time at the buffer. The data set consists of different vehicle types; however, to simplify only trucks and trailers are included. Trucks will include all vehicles under 8 meters, this include vans and personal cars. The number of cars in the data set is very small only a few arrivals were noted. Trailers include all vehicle longer than 8 meters.

Besides the given data there are important aspects on which data is missing. These aspects are the transportation times to and within halls, the number of pallets or amount of goods within the trucks, the loading/unloading times of the vehicles and the percentage of self-loaders. To obtain these data measurements are performed on multiple days during a convention. After the measurements certain data is still lacking. For these aspects assumptions have been made based on knowledge from the RAI.

3.4.2 Performed Measurements and Insights

To obtain more data measurements were performed during the Aquatec convention. This is a large convention that covers almost the entire complex of the RAI. The set-up of the experiment can be found in Appendix B The obtained data from these measurements are:

- Arrival times of trucks and trailers
- Actual time truck or trailer starts unloading
- Departure time of trucks and trailers
- Time it takes to unload pallet from truck per vehicle type (Forklift, EPT, pallet jack)
- Vehicle speed per type (Forklift, EPT, pallet jack) within hall on yellow path
- Vehicle speed per type (Forklift, EPT, pallet jack) within hall on normal path

While performing these measurements insights were gathered about the logistic processes at the RAI. The following insights were obtained.

- Vehicles frequently exceed the maximum loading and unloading times, which are 60 minutes for a trailer, 45 minutes for a truck and 30 minutes for a van. The staff working on the work sites stated that it is hard to keep track of these times and at the same time arrange all the new incoming vehicles. Most vehicles that exceeded the time limit did not receive any warnings or measures.

- Most vehicles are loaded or unloaded one pallet at a time by the driver or the logistic partner. Transporting a pallet can take minutes depending on the moving speed and the situation within the hall. This means that a truck with many pallets easily exceeds the maximum loading time. During the measurements some vehicles took more than two hours to load or unload. Besides loading and unloading some truck drivers help with stand building and they leave the truck on the unloading spot. They only come back to the truck when they need a pallet and use the spot at the working terrace as a parking place.

- Trucks that are unloaded by themselves (self-loaders) can start immediately with the loading and unloading process. However, trucks that are unloaded by the logistic partner have to wait until it is their turn and a forklift is available. In practice this waiting time differs from a few minutes up to an hour.
- The RAI has entry doors to every hall. However, not all doors were open on certain days. After asking why this was the case, it appeared that the reason for this are the costs of opening an extra door. An extra security guard has to be available to guard the door. On the other hand, leaving a door closed decreases the efficiency of the logistic processes since detours have to be taken and congestion occurs at the only open door.
- The yellow paths should be free of obstacles; however, this is not always the case Figure 3.6. Within the halls staff should be checking on this to keep the safety precautions in order. However, it showed that keeping the yellow path free of objects is harder than expected and not all stand builders take this seriously. Besides the better flow for logistics the yellow paths are also there for safety requirements. Blockage of these paths reduces safety and can give problems when a safety check is executed.
- Non yellow paths are often full with objects making it hard to transport incoming goods over these paths. The transporter first has to move the objects to free the path before the path can be passed, this causes longer travel times within the hall Figure 3.6.
- Since the yellow path is often better accessible than the other paths this path is also used as the main transport route. This means that most people and forklifts use this path to transport their goods from the truck to the stand. Due to this fact the yellow paths are very crowded and it often occurs that forklifts have to pass each other while space is limited. Forklifts have to wait, move backwards or manoeuvre into an open space next to the path in order to let each other pass.

(a) Yellow path (b) Normal path

Figure 3.6: Situations on paths

3.4.3 Assumptions

Besides the available and measured data there is still data missing. Two important aspects on which data is missing are the share of self-loaders and the load per vehicle. Since there is no data available and was hard to collect with measurements assumptions are made. These assumptions are made by the traffic managers from the traffic department of the RAI. Due to their experience with the logistics at the RAI these assumptions should be close to the reality; however, this can not be validated. As mentioned before every convention is different which means that the number from these assumptions would also differ for every convention. The traffic managers tried to determine the average value for all conventions.

In Table 3.1 the assumed percentages of self-loading and non self-loading vehicles can be seen for both trucks and trailers. It shows that a trailer uses the logistic partner more often than a truck. This is expected since a trailer is larger and probably contains more goods. The logistic partner can use forklifts, which makes the unloading faster and easier.

Table 3.1: Share of self-loading and logistic partner trucks and trailers

Loader/Vehicles	Trailers	Trucks
Percentage self-loader	30%	80%
Percentage logistic partner	70%	20%

The assumed load for trucks and trailers can be found in Table 3.2. The percentages show that a trailer is more likely to contain a large load compared to the smaller trucks. This makes sense since for small loads a smaller vehicle is desired instead of a large vehicle due to the costs.

Table 3.2: Share of loads per vehicle type

Load/Vehicles	Trailers	Trucks
$<$5 Pallet	10%	30%
5-10 Pallets	30%	60%
10-20 Pallets	30%	10%
$>$20 Pallets	30%	0%

3.5 Conclusion

To answer sub-question 3 section 1.6: *How is freight currently transported to, from and within the RAI and why is it not optimal?*

Communication is an important factor at the RAI since many stakeholders are involved. Both communication within the RAI and to external partners could be improved to decrease inefficiencies. A better cooperation between the logistics outside the hall and inside the hall should be established to organise the logistics in an efficient way. The communication between the RAI and stakeholders such as transporters and logistic partners is also of importance. The RAI has started improving their communication with involved parties by introducing online traffic regulations. On the other hand, communication from transporters and logistics partners to the RAI should be improved. In the current situation most information about arrivals of trucks and trailers and their loads is unknown before they arrive. This causes peak-behaviour and extensive waiting times.

In the current situation vehicles enter the RAI via the north side or the south side. The vehicles delivering on the north side are a burden for the residents since they cross the residential area and the unloading takes place in their sight. During large conventions the logistic space at the RAI is insufficient; therefore, a buffer area is constructed and operated on busy days. This buffer are reduces the peak behaviour. However, the buffer area does not solve the waiting times and queues of waiting vehicles, it only relocates the queues.

Arriving trucks and trailers are unloaded one pallet at the time, this means that the pallet first has to be delivered or picked-up first before the next pallet can be unloaded. This process if very time consuming and leads to trucks and trailers often exceeding the maximum unloading times often. Longer unloading times ensure a longer unloading spot occupation, which reduces the capacity at the RAI.

The logistics at the RAI suffer from inefficiencies due to the following aspects. Too many vehicles drive through the residential area on the north side causing nuisance, loading and unloading times often exceed the maximum time limit, which decreases capacity and communication between involved parties is lacking. To analyse the system and determine its performance, six key performance indicators are identified. These indicators will be used in chapter 4 to determine the performance.

Part III

Analyse

4 | Analysis

To answer sub-question 4 (section 1.6)s and determine the performance of the current logistics system an analysis of the current system is performed. To be able to determine the performance of the system the collected data is analysed and discussed. The current situation will be simulated and the model will be verified and validated with the analysed data.

4.1 Data Analysis

To be able to analyse the current system obtained data is analysed. Data collected by the RAI will be used. This data was collected during a big convention the PLMA. Also, the data collected by performing measurements in the field will be analysed (Appendix B). The following subjects will be discussed: arrival data, destinations, unloading behaviour, movement speed within halls and the capacity on the work sites.

4.1.1 Arrival Pattern

The arrival pattern of trucks and trailers gives insights into the peak moments. The logistics has to be able to handle these peak moments. If peaks are too high the capacity at the RAI can be exceeded and waiting times of trucks and trailers increase. To be able to get a better understanding on the arrival behaviour arrival data is analysed.

In Figure 4.1 the arrival process of trucks and trailers can be seen during a busy build-up day at the RAI. In general all build-up days show similar patterns. The highest peak of arriving vehicles lies in the morning, between 7 and 11 a.m. Within this time block 62% of the total amount of arriving vehicles arrives. At 3 p.m. the last vehicles arrive and no further arrivals take place after that. On a standard day the RAI is open for logistics between 7 a.m. and 7 p.m. this means that there are 12 hours available for logistics. Currently arrivals only take place between 6 a.m. and 3 p.m., which only covers 10 hours. This means that two hours of logistic operational time are unused. During this particular day the highest noted peak is seen at 10 a.m. with 53 arriving trucks and trailers. If all arriving vehicles would be evenly divided over the day the peak would be reduced to 23 trucks and trailers per hour. This number is calculated by dividing the total number of trucks and trailers by the amount of hours the RAI is open for logistics. Extending the operational times even further to 14 or 16 hours reduces the pressure on the logistics system even more. Spreading trucks and trailers evenly over the day reduces the arrival peaks. However, it increases the amount of arrivals during currently calm hours.

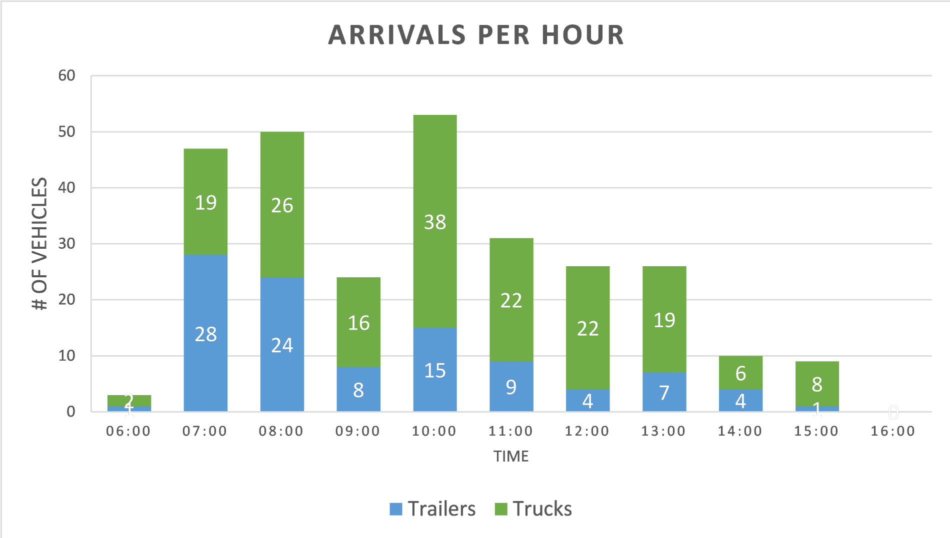


Figure 4.1: Arrivals per hour

4.1.2 Destinations

The arriving vehicles at the RAI have a certain work site as destination. This destination depends on the hall they are delivering for. The load of a truck or trailer is assigned to one or multiple stands, which are located within a certain hall. In Figure 4.2 the percentages of the destinations are given. The data of the PLMA is used to obtain these percentages. The PLMA occupies the entire RAI and gives a clear overview on the division of the destinations.

As can be seen in Figure 4.2 most trucks and trailers deliver loads for hall 1, 5, 7 and 8. This is expected since these are the largest halls of the RAI. Large halls can fit more stands, which requires more building materials, furniture and decorations. Hall 1, 5 and 7 are located on the north side and hall 8 on the south side. Hall 4 has no incoming vehicles since this is a building instead of a hall where smaller meetings take place. Halls 2, 3, 6 and 9 are smaller halls and therefore have a smaller share in the number of arriving trucks and trailers.

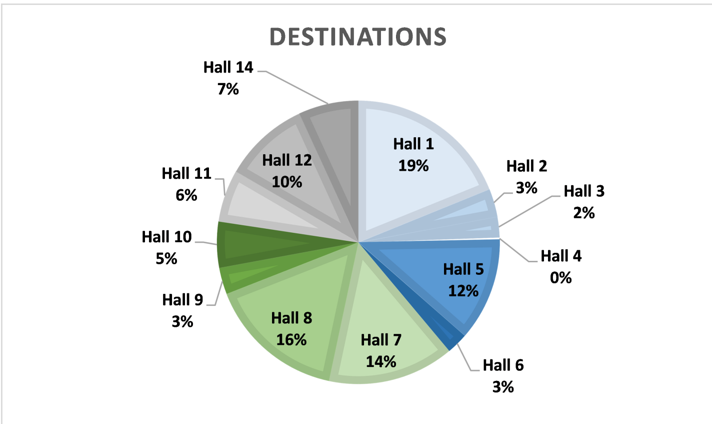
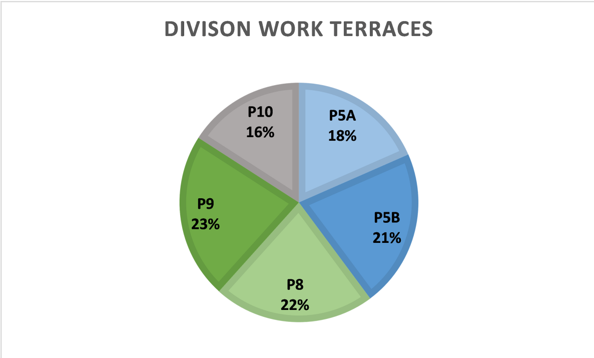
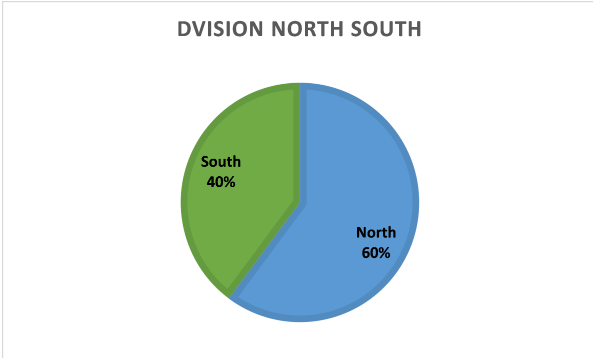


Figure 4.2: Destinations

To start the unloading process trucks and trailers need to enter a work site. Depending on the hall the working terrace is chosen. Which halls are served by a certain working terrace can be seen in Table 4.2 and Table 4.3. Within Figure 4.3a the division of the working terraces is shown. It shows that the trucks and trailers are distributed fairly even over the five working terraces. The P9 and P8 on the north side are mostly visited followed by the P5B on the south side. This division is expected since these are the working terraces that serve the biggest halls. he P8, P9 and P10 are located on the north side and receive 60% of the arriving vehicles. The south side (P5A and P5B) receive 40% of the arriving vehicles.



(a) Division work sites



(b) Division North South

Figure 4.3: Division work sites

4.1.3 Unloading Behaviour

During two events measurements were taken to gain insight into the time trucks and trailers occupy the unloading spot. The exact details on how these measurements were obtained can be found in Appendix B The data obtained on unloading times is limited and can therefore not be statistically tested. To verify the measured numbers these were discussed with the traffic managers at the RAI and there prior research at the RAI was looked into.

Trucks and trailers at the RAI have two choices with regard to the unloading process. They either choose to unload the vehicle by themselves or they use the services of the logistic partner. The logistic partner is allowed to operate forklifts and EPTs whereas the self-loaders are only allowed to use hand pallet-jacks. Prior research showed that there is no clear difference between unloading times of self loaders and logistic partners (Hoogland, n.d.). Therefore the unloading times of self-loaders and logistic partners can be assumed to be similar.

The RAI has standard maximum unloading times. For trailers the maximum unloading time is 60 minutes and for trucks 45 minutes. If vehicles exceed the maximum time they risk being towed away and being fined. However, in practice this rarely happens. In Figure 4.4 the average measured unloading times for trucks and trailers is shown. As can be seen these average times exceed the maximum allowed time. This means that in general trucks and trailers occupy unloading spots longer than the RAI allows. The total unloading times are comprised of two parts there is the waiting time at the spot before the unloading process starts and the actual time to unload the goods.

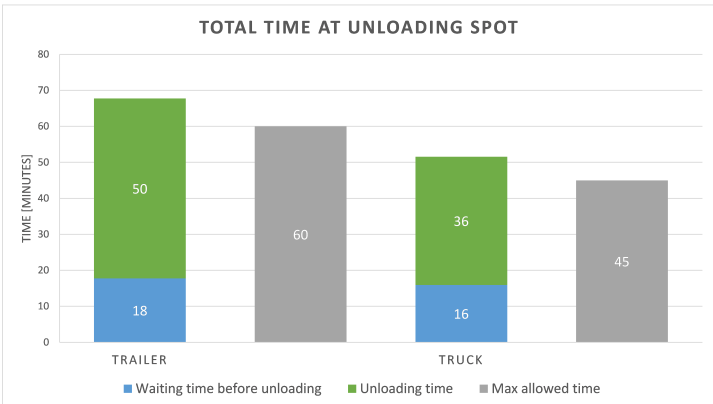


Figure 4.4: Average total time vehicles spend at loading spot

The average unloading time for trailers is measured at 68 minutes and for trucks 52 minutes. After discussing these measurements with the traffic managers these values seemed too low, especially for the trailers. Within the data set of the PLMA the entrance times of trucks and trailers are noted, for trailers the departure times at the RAI site are also noted. With this data the time that the trailer was at the RAI site can be calculated. This data was collected for 379 trailers and the average time found is 95 minutes. After consulting the traffic managers about the obtained values from both the measurements and the existing data the values for the unloading times are set, these can be seen in Table 4.1. These set values will be used to verify and validate the outcomes of the simulation model.

Table 4.1: Set average unloading times

Vehicles	Trailer		Truck	
	Self-loader	Logistic partner	Self-loader	Logistic partner
Average unloading time (minutes)	95	95	60	60

4.1.4 Speed within Halls

The unloaded goods have to be transported to the final location within the hall. This transport can be done by hand with a pallet jack or with forklifts and EPTs. Within the halls there are two types of paths yellow paths and normal paths. To be able to determine the speeds of the vehicles on the two types of paths, measurements were performed within the hall.

The situation within the hall changes every day. During the first days of the build-up the halls are still empty and paths are free. The further the build-up is progressing the fuller the halls become. During these days the halls are very chaotic and paths are often blocked by obstacles. Because of this higher speeds are expected within the hall during the first day of the build-up and lower speeds near the end of the build-up. The measurements on the speeds are obtained late in the build-up process. The speeds are obtained by recording the movement time of the forklift, EPT or pallet-jacks and the measured length of the movement. This means that the speed is not measured at a certain point but over the whole route so the average speed of the movement is calculated. A more extensive overview on how the measurements are obtained can be found in Appendix B

In Figure 4.5 the average, minimum and maximum speeds are shown, per vehicle type, for both the normal path and the yellow path. The EPT measurements include only drivable EPTs, the manual EPTs (electric pallet jacks) are included under the pallet jacks.

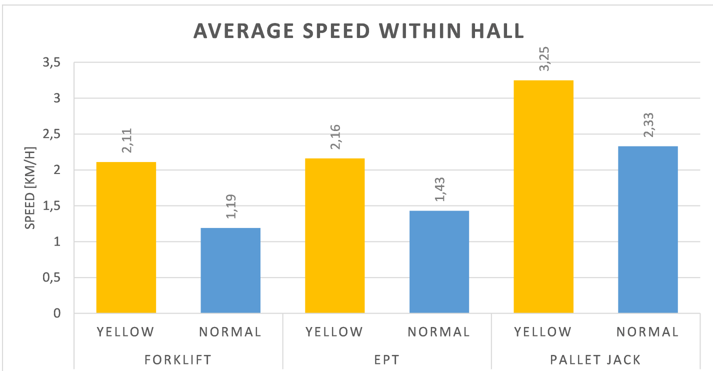


Figure 4.5: Average moving speed in hall

An interesting outcome is that the pallet jack is overall the fastest transportation tool. A pallet jack can be manual or electric; however, it has to be pulled by a human. A reason for this difference could be that forklifts and EPTs require more space and have more difficulties turning and avoiding obstacles. Forklifts and EPTs also have to wait when another vehicle is coming since they are not able to pass each other on the paths. A pallet jack fits on the side of a path, so it can let a vehicle pass and only has to wait a few seconds for the passing forklift or EPT. Compared to the forklift the EPT has a slightly higher average speed. This is expected since an EPT is easier to steer than a forklift and the driver has better vision.

The speed on the yellow path is slightly higher compared to the normal path, namely around 1 km/h. A higher speed on the yellow path is expected since these paths should be free of obstacles. However, a larger difference was expected since these paths are meant for faster transport. There are several reasons why the speed difference is not as large as expected. Two reasons found for this are: yellow paths are not always obstacle free and due to the high utilization the chance of vehicles passing each other increases. Yellow paths are expected to be faster, which leads to a high utilization.

4.1.5 Capacity work sites

To determine the current capacity of the RAI maps of the work sites are used and knowledge of the traffic managers. The RAI has five main work sites which are the P10, P9, P8, P5A and P5B Figure 1.2. These work sites are used for the unloading of trucks. During full complex events the P8 is separated into different parts since a pavilion is constructed on the work site Figure 4.6. This pavilion is used to increase the available hall space. Besides the construction of the pavilion, storage tents are also constructed on the P5A, P5B and P10. These tents are constructed on existing unloading spots. For this reason the capacity on the work sites can differ per event.

In Table 4.2 the maximum capacity of the RAI is shown and the halls served by the working terraces are shown. This capacity is based on the maximum number of trailers and trucks that fit on the work sites. The maximum number means that all unloading spots are available and none of them are blocked by objects or tents. The total capacity is 60 trailers and 134 trucks. A trailer spot can also be occupied by a truck (or two) so these numbers are only an indication. The share of the total capacity on the north side (P8, P9, P10) is 58%.

Table 4.2: Maximum capacity working sites

Working terrace	P10		P9		P8		P5A		P5B	
Serving halls	6, 7		1, 2, 3, 4, 5, 6		1, 2, 3, 5		10, 11, 12		8, 9, 10	
Capacity	Trailers 8	Trucks 14	Trailers 9	Trucks 6	Trailers 25	Trucks 50	Trailers 10	Trucks 34	Trailers 8	Trucks 30

The maximum capacity is the capacity in an ideal situation. However, during busy events when a high capacity is needed the capacity is decreased due to storage tents and pavilions. Due to the construction of a pavilion on the P8 the work site is divided in two smaller work sites which are the P8A and P8B. In Table 4.3 the capacity during full events is shown. The total capacity is 46 trailers and 58 trucks. This means that the total capacity decreased with 54% compared to the maximum capacity. The share of the north side is 45 %, which means that the capacity on the north side decreased more than the capacity on the south side.

Table 4.3: Actual capacity during full complex event

Working terrace	P10		P9		P8A		P8B		P5A		P5B	
Serving halls	6, 7		1, 2, 3, 4, 5, 6		14		1,2,3		10, 11, 12		8, 9, 10	
Capacity	Trailers 6	Trucks 6	Trailers 9	Trucks 6	Trailers 8	Trucks 6	Trailers 6	Trucks 0	Trailers 9	Trucks 24	Trailers 8	Trucks 16

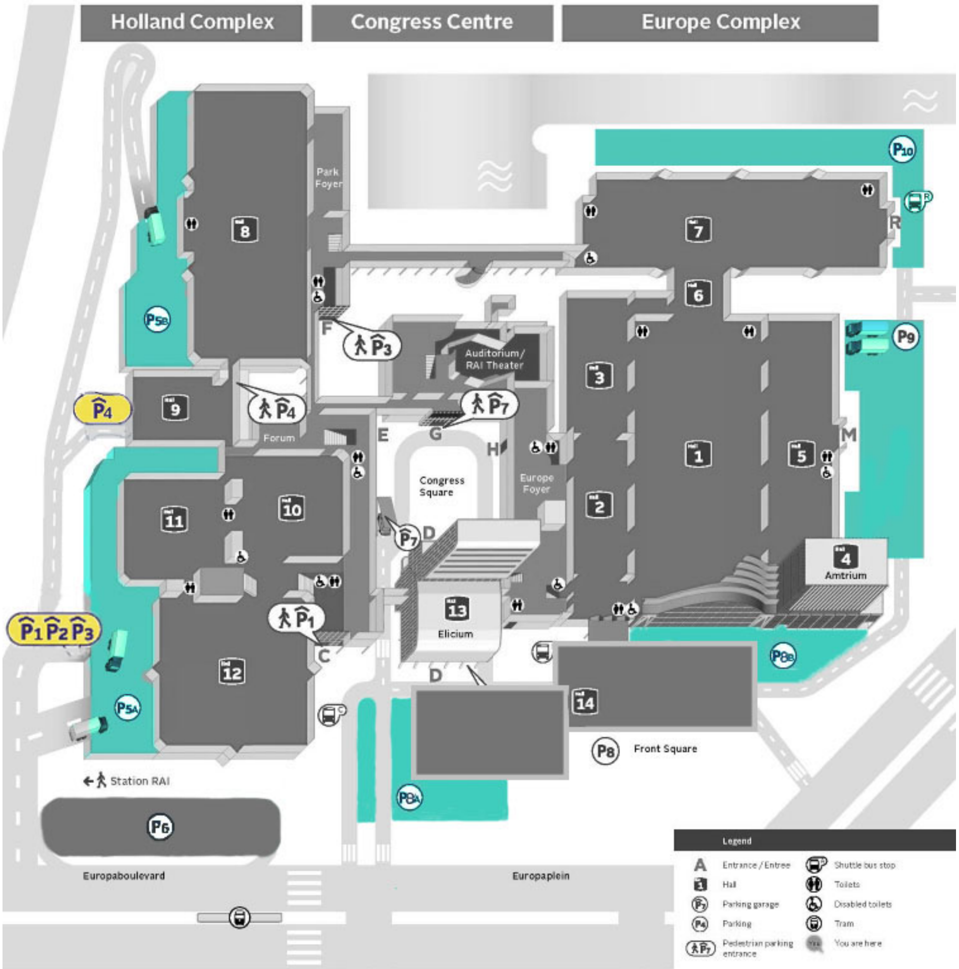


Figure 4.6: Map including pavilion (Hall 14) and loading/unloading zones

4.2 Conceptual Model

With the use of the simulation program Simio a model is made of the current situation. The model is used to obtain certain outputs based on inputs and controls. In Figure 4.7 the inputs, outputs and controls are shown.

The controls can be changed for sets of runs in order to run different scenarios and do tests. The fleet size of EPTs and forklifts can be adjusted to see the effect of these changes. Apart from the number of forklifts and EPTs the speeds of these vehicles can also be adjusted. The arrival process of the vehicles can be adjusted by changing the arrival slot-times. The infrastructure can be adjusted. This means that the number of loading spots and where these are located can be changed.

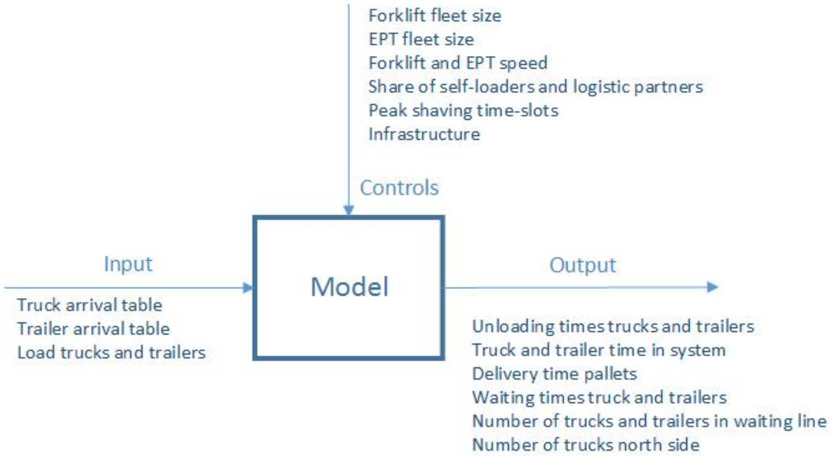


Figure 4.7: Model inputs, outputs and controls

In Figure 4.8 the conceptual model of the current situation is shown. This conceptual model is used to gather insights in how to model the unloading process within the simulation. In the current situation trucks and trailers arrive at the RAI surroundings and drive to the right entrance. At this entrance they are checked in and registered. After the check and registration the truck or trailer is assigned to an unloading spot. However, it can occur that all spots are occupied. In this case the trailer or truck has to wait in the waiting queue. As soon as a spot becomes available the truck or trailer is assigned to it. The trailer or truck drives to the spot and parks. After parking the truck or trailer is ready to start the unloading process. This process differs for self-loaders and logistic partner users. If the truck or trailer is a self-loader the unloading is carried out by hand. For unloading with the logistic partner a forklift is used. After unloading the pallet it is transported to the final destination either by hand or by forklift depending on the unloading type. If all pallets are delivered the truck departs and eventually leaves the RAI surroundings.

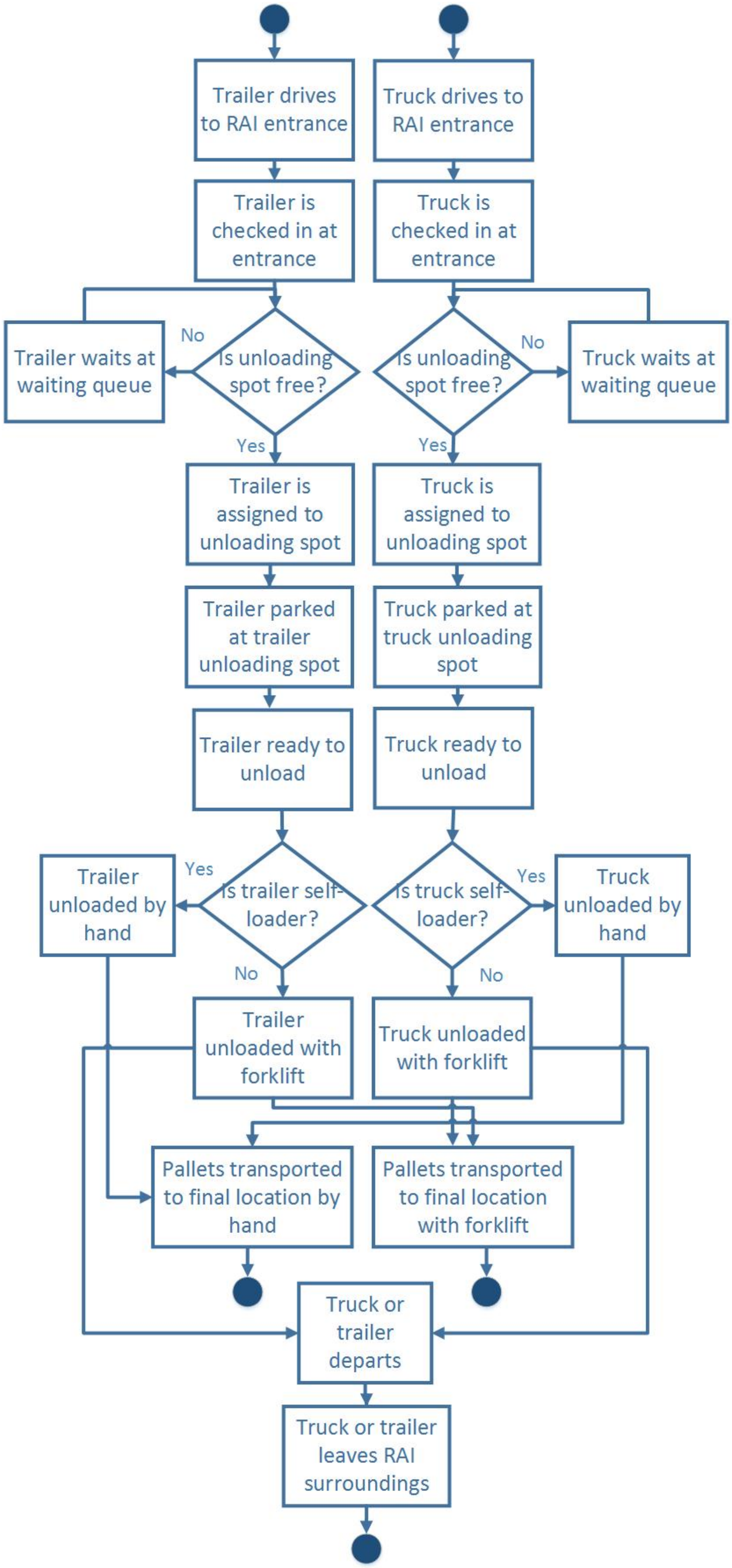


Figure 4.8: Conceptual model current situation

4.3 Model Assumptions

To be able to model the current situation several assumptions had to be made. These assumptions are necessary since it is not possible to capture all aspects of the current situation in detail.

1. The number of unloading spots is set on a fixed number for every work site according to the number shown in Table 4.3
2. Certain unloading spots in the model can only be used by trucks and others by trailers and trucks.
3. Only two type of vehicles are included, trailers and trucks. Trailers represent vehicles >12 meters and trucks vehicles < 12 meters.
4. The share of self-loaders is based on the assumptions by the RAI, Table 3.1.
5. Trucks and trailers arrive according to the existing data without any randomness.
6. Incoming trucks and trailers are signed in at the gate, which takes around 30 seconds up to 2 minutes.
7. The load of trucks and trailers is based on the assumed load share given by the RAI, Table 3.2
8. A truck or trailer can only deliver once. This means that multiple visits by the same truck or trailer to different halls at the RAI is not possible.
9. When trucks or trailers arrive at the unloading spot it takes between 1 or 15 minutes before they start the unloading process.
10. All goods arrive on pallets.
11. Trailers and trucks are unloaded one pallet at a time. Multiple forklifts can work on the same trailer or truck.
12. the maximum number of forklifts is set at 40 in total. This number is based on the number given by the logistic partner of the RAI.
13. Loading a pallet on a forklift from the truck or trailer takes between 30 seconds and 4 minutes.
14. Every pallet is delivered to a random sink, which stands for a stand within the hall. An unloading spot has a list of sinks it can choose from.
15. Forklifts and EPTs choose the shortest path.
16. Unloading a pallet from the forklifts takes between 30 seconds and 1 minute.
17. Forklifts drive outside the halls with a speed of 5 km/h and near trucks and trailers with 2.5 km/h.
18. On the yellow path maximum allowed speed is 5 km/h and on the normal path maximum speed is 2.5 km/h.
19. Forklifts speed within halls are set between 1.5 and 4.2 km/h.

Assumption 1 till 3, 5, 8, 14, 15 and 18 are made to simplify the model. The number of unloading spots within the simulation model is fixed. However, in the real situation the RAI has no fixed unloading spots. The traffic employees park trucks and trailers based on experience and where they see space. Some employees can fit more trucks and trailers than others. The fixed number of unloading spots is based on the knowledge of the traffic managers. The model is limited to two types of trucks and trailers. Normally more vehicle types enter the RAI for unloading such as vans and cars with trailers. Since the amount of vans and cars with trailers was limited within the data set they are handled as trucks. The trucks and trailers arrive according to the data set without any randomness. Including randomness would require more data input for the model. Assumption 4, 7, 11 and 12 are based on information given by the traffic department at the RAI and the logistic partner. The RAI is a highly flexible environment and depending on the convention it is assumed that the values of the assumptions differ. However, the given values are expected to represent most convention types. The number of forklifts used during the PLMA convention, which is the convention of the used data set, is 63. However, not all 63 forklifts are used for the unloading of trucks and trailers. Several forklifts are used to transport goods from and to the storage and some forklifts are unused since the driver is on a break. Therefore the estimation is made that a maximum of 40 forklifts operate on the unloading of trucks and trailers at the same time. Assumptions 6, 9, 13, 16, 17 and 19 are based on collected data. This data is obtained by performing several experiments at the RAI Appendix B. A clear overview of all inputs of the simulation model can be found in Appendix E.

4.4 Model Design

The model of the RAI is made with the use of an exact floor plan of the RAI. Due to this fact the halls and work site are built on scale and represent the real world dimensions. Within the model there are two types of networks, which are represented by links and nodes. One network is used by trucks and trailers and the other network by forklifts, EPTs and pallet jacks. The trailer and truck networks connects the input of trucks and trailers to the unloading spots and to the exit. The network for forklifts connects the unloading spots of trucks and trailers with the stands in the hall. Normally hundreds of stands are constructed within the halls of the RAI, including these stand within the model would make the model too detailed and complex. Therefore a decision is made to model only a few points in the hall that represent multiple stands. A complete overview of the floor plan of the model can be seen in Figure 4.9. A more detailed overview of the lay-out of the work sites can be found in Appendix D

Trucks and trailers are generated by a source, which leads to a road that enters the RAI (bottom left). The generation is based on existing arrival data or generated data sets. The main data that is used is the data of a real convention the PLMA. Based on this data several other data sets are generated to be able to run different scenarios (Appendix F). The data sets consists of the arrival time and the destination of the truck or trailer. The destination is always one of the five work sites. After generating the truck or trailer properties are assigned to the truck or trailer such as: is it a self-loader or uses the logistic partner and the number of pallets it is holding. Within the model there are four types of trucks: Trailers and trucks which can be either a self-loader or a logistic partner. Within the model these different types are represented by a different colour Table 4.4. The visual representation in the model of the different vehicle types can be seen in Figure 4.10a

Table 4.4: Truck and trailer types

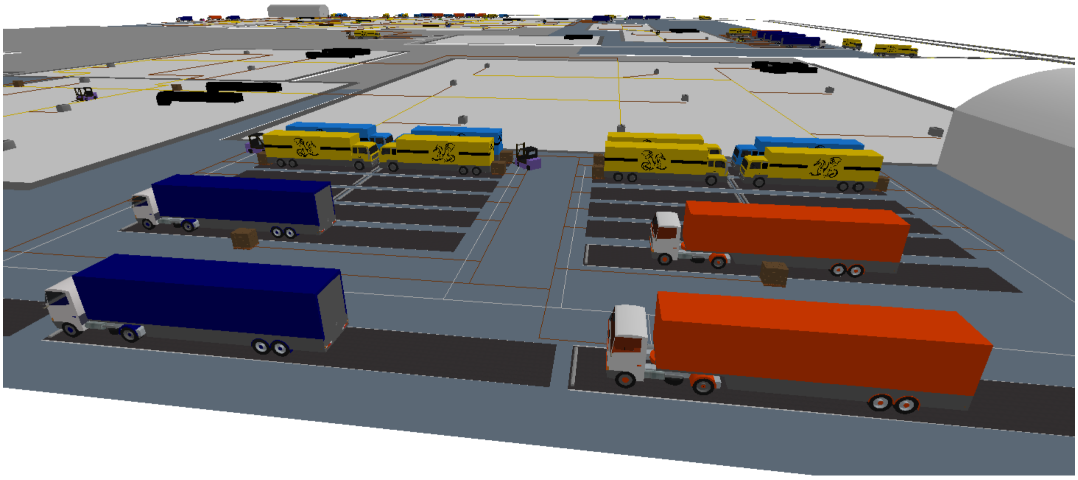
Vehicle type	Trailer		Truck	
	Self-loader	Logistic partner	Self-loader	Logistic partner
Colour	Orange	Dark blue	Yellow	Light blue

There are three main entrances: the south side, north side and the middle. The middle entrance is considered to be located at the north side of the RAI and is only used during large conventions. During small conventions it is only used as an exit. Trucks and trailers arrive at an entrance depending on the work site they are heading for. At the entrance the trucks and trailers are registered and checked. This process takes approximately half a minute to two minutes. After the check the truck or trailer is allowed to enter an unloading spot. If no spots are available the truck or trailer has to wait at the entrance queue until a spot becomes available. The truck or trailer enters the unloading spot, which is modelled as a separator. At the separator the pallets are separated from the trucks and trailers. The amount of pallets that are separated is depending on the vehicle type and is generated based on the assumptions from the RAI. A trailer has a higher chance of possessing more pallets than a truck since trailers are larger and more likely to transport a high amount of pallets. As soon as the truck arrived at the unloading spot a certain time passes until the unloading process starts, due to inefficiencies in the process. These inefficiencies can for example be that the driver first has to find the stand or the staff to help unload. This time takes approximately one minute to fifteen minutes. As soon as the unloading starts the pallets are separated from the truck or trailer and are then either picked up by a forklift or self-transported, depending on the vehicle type. When a pallet is transported by the logistic partner, an actual forklift picks it up, and the pallet is visually seen on the forklift. When a self-loader is transporting the pallet only the pallet is moving by itself Figure 4.10b.

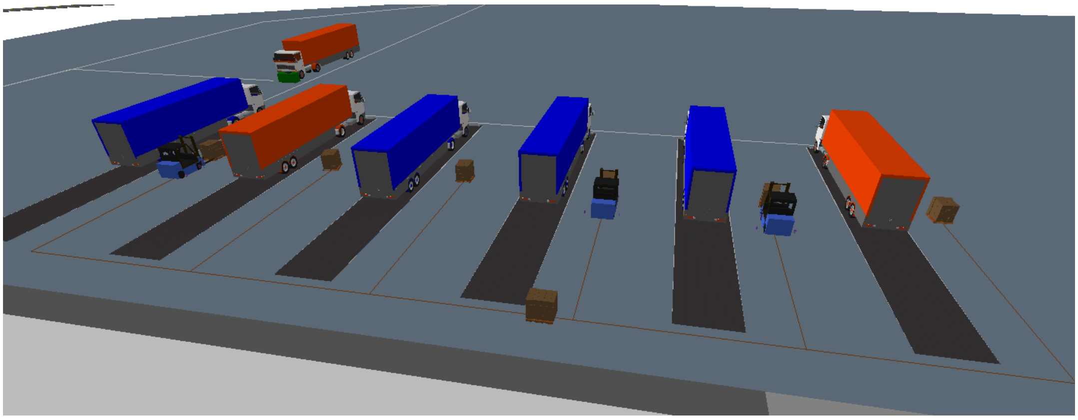
Every work site has its own forklifts. During the simulation the number of forklifts is fixed, before running it is possible to adjust the number of forklifts. The speed outside the halls is fixed on 5 km/h; however, in the hall a random speed is given to the forklifts. This random speed is implemented to simulate the situation within the halls, at certain times paths are blocked resulting in lower speeds. Within the halls there are paths with a speed limit of 2.5 km/h and 5 km/h, forklifts can never exceed these maximum path speeds.

Pallets are transported to the sinks within the halls, which represent the stands. Depending on the work site there are dedicated halls, which are served by the work site. Every unloading spot has a list of all sinks that are represented in the halls that they serve. The destination is picked randomly from this list. As soon as the pallet is delivered to the sink the pallet entity is destroyed. Picking up the pallet and dropping it off takes time. The assumed times for these pick-ups and drop-offs can be seen in Appendix E. As soon as the pallets are unloaded the truck or trailer leaves the unloading spot and drives to the exit following the infrastructure leading to the exit where the truck or trailer entity is destroyed (bottom left). An overview on the input values of the simulation models can be found in Appendix E. In Figure 4.9 examples are shown of the simulation model. It shows the different truck and trailer types, the unloading spots, the pallets and the forklifts.

Figure 4.9: Model overview



(a) 3D overview P5A



(b) 3D overview P8

Figure 4.10: 3D representation of work sites

4.5 Verification and Validation

The outcomes of a simulation model are often used to make important decisions. Before these decisions can be made it is important that the model is verified and validated. Verification is defined as: *"ensuring that the computer program of the computerized model and its results are correct"*. Validation is defined as: *"substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"* (Sargent, 2010). In other words with verification there is checked if the model is correctly modelled and with validation it is checked if the model corresponds with reality.

4.5.1 Verification

To be able to verify the simulation model two approaches are used. First certain general checks are described and there is checked if the simulation passes these checks. Second different scenarios are run and a check is done on the behaviour of the model to see if it behaves as expected.

The following general checks are defined:

- Logistic partner trucks and trailers are unloaded with a forklift, self-loaders are unloaded by hand without a forklift.
- Forklifts and self-loaders can only transport one pallet at the time.

- The load of trucks cannot be higher than 15 pallets, the load of trailers cannot be higher than 20 pallets. And the minimum load is 5 pallets.
- Forklift speeds outside halls cannot be larger than 5 km/h.
- Forklift speeds within halls are within the random distribution 1.5-4.2 km/h.
- All trucks and trailers should be unloaded only once and should leave the model when they are done.
- The pallet and vehicle type share should comply with the defined probabilities.

To be able to see if the model passes these general checks two methods are used. A visual approach is used. In this approach the animation of the simulation model is used to explore and see the behaviour of the different objects within the simulation model. The second method is the usage of the generated output data to verify the general checks. With visual checks and output checks it can be said that the model passed all general checks.

To further investigate the behaviour of the model different scenarios are run. These scenarios are used to see if the behaviour of the model is as expected. The number of replications is determined with the use of two methods the graphical method and the confidence interval method (Appendix D) and is set at 25 replications. To see if the model behaviour is as expected different runs are done where a certain input variable is adjusted. These input variables are for example the amount of forklifts and the moving speed of forklifts. By adjusting these input variables the outputs of the model change. The outputs are checked to see if the model behaves as expected when certain inputs are adjusted. In Table 4.5 the different inputs per scenario can be seen. For the trailer and truck load the assumed divisions are used except for the last two scenarios. This division can be seen in Table 3.2

Table 4.5: Verification scenario inputs

Scenario	# Forklifts	Max forklift speed (km/h)	Forklift speed hall (km/h)	Self-loader delivery time (min)	Trailer load (# pallets)	Truck load (# pallets)
Base	40	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(2,12)	5/10/15/20	5/10/15
Half the forklifts	20	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(2,12)	5/10/15/20	5/10/15
Double the forklifts	80	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(2,12)	5/10/15/20	5/10/15
Low forklifts speed	40	2.5	Rand.Uniform(0.75,2.1)	Rand.Uniform(2,12)	5/10/15/20	5/10/15
High forklift speed	40	5	5	Rand.Uniform(2,12)	5/10/15/20	5/10/15
Half self-loading time	40	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(1,6)	5/10/15/20	5/10/15
Double self-loading time	40	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(4,24)	5/10/15/20	5/10/15
Low loads	40	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(2,12)	5	5
High loads	40	5	Rand.Uniform(1.5,4.2)	Rand.Uniform(2,12)	20	15

In Table 4.6 the outcomes for the different scenarios can be seen. The outputs that are included are three of the KPIs, which are the average unloading times of trucks and trailers, the max waiting time that occurred during the simulation runs for a specific truck or trailer and the average delivery time of pallets. The unloading time is measured for trucks and trailers, which are further divided in self-loaders (SL) and logistic partner users (LP). The first scenario is the base scenario where the standard values of the model are used.

When the number of forklifts decreases we see an increase in the unloading times of the logistic partner trucks and trailers. This is expected behaviour since the pallets from these trucks and trailers are unloaded and transported with the use of forklifts. If less forklifts are available and they still have to serve the same amount of trailers and trucks the process will take longer. If the unloading process takes more time the unloading spots are longer occupied, which results in high waiting times, this can also be seen in the outcomes. The delivery time of the pallets increases since the pallets wait longer on a forklift to be picked up and delivered. When the number of forklifts is doubled compared to the base scenario we see a decrease is unloading, waiting and delivery times. When the forklift speed is decreased we expect longer unloading times and delivery times since a forklift is longer occupied with one delivery. This results in a longer overall unloading time for the logistic partner trucks and trailers. When the forklifts speed is increased a faster unloading time is expected. The outcomes within these scenarios follow the expected behaviour. The number of forklifts and the forklift speed have limited influence on the unloading times of self-loading vehicles. This is the case since self-loaders unload the vehicle by hand and are not allowed to use the forklifts. Increasing the number of forklifts will therefore not increase the unloading time of self-loaders.

After the variations with forklifts the self-loading times are varied. This time stands for the time it takes for the self-loader to unload the pallet and transport it to the location within the hall. If the self-loading times is decreased with fifty percent we see a decrease in the unloading time of self-loaders. And when the self-loading time is doubled an increase in self-loading time is seen. Adjusting the self-loading times also increases or decreases waiting times. When trucks or trailers have longer unloading times they occupy an unloading spot longer. This longer occupation reduces the overall capacity since less vehicles can be handled in the same time. Due to this lower overall capacity arriving trucks or trailers have a higher chance to wait for a free unloading spot. These outcomes are in line with the expected behaviour.

Finally two scenarios showed the behaviour when the load of trucks and trailers is adjusted. When looking at the outputs it is clear that a lower truck and trailer load leads to lower unloading, waiting and delivery times. This makes sense since less pallets have to be transported, which takes less time.

Overall it can be said that the model behaves as expected on the changes made to several input variables. Also, the behaviour of the KPIs seems like logical behaviour. Therefore, it can be said that the model shows correct behaviour.

Table 4.6: Verification scenario outcomes

Scenario	Average unloading times (min) (SL = self-loader, LP = logistic partner)				Average waiting time (min)	Average delivery time (min)
	Trailer SL	Trailer LP	Truck SL	Truck LP		
Base	98	92	64	66	16.9	52
Half the forklifts	101	211	64	236	65.1	104
Double the forklifts	100	51	64	34	2.5	39
Low forklift speed	103	183	65	171	69.9	86
High forklift speed	97	71	65	50	6.0	45
Half self-loading time	54	93	36	66	8.7	39
Double self-loading time	189	88	121	69	23.7	76
Low loaded trucks and trailers	36	23	36	23	0.1	21
Full loaded trucks and trailers	142	158	107	152	64.8	79

4.5.2 Validation

Validation checks whether the model corresponds with reality. In an ideal situation the validation is done with the use of real-world data. The outputs of the model are then compared to the existing data. Since the RAI has little data available and the data differs for every convention or event, a comparison between real-world data and system outputs is difficult. To be able to validate the model the available data is checked and the knowledge of the traffic manager working at the RAI is used. For the comparison the base scenario of the model is used. This scenario tries to replicate the real world as much as possible.

There is only one KPI which can be calculated with the available data set. This is the nuisance, which is defined as the amount of trucks and trailers that enter the north side of the RAI and unload there. The north side includes both the vehicles that enter via the north entrance and the middle entrance. As mentioned before 61% of the vehicles enter the north side and 39% enter the south side.

Another KPI of importance is the unloading times of trucks and trailers little information is available within the data set. From the 1629 trucks and trailers in the data set the arrival and departure time were only noted for 379 trailers. This means that there is no complete data set on the unloading time of trucks. The average time, calculated with the data set, a trailer stayed at the RAI was 95 minutes. In the data set there is no difference between self-loaders and logistic partner users. However, in prior research done the RAI there is stated that there is no difference in the staying time of self-loaders and logistic partner users (Hoogland, n.d.). Therefore the average unloading times used for validation for trailers both self-loaders and logistic partner users is set at 95 minutes. Since there is no data on the unloading time of trucks an estimation had to be made. This estimation is made based on knowledge of multiple traffic managers at the RAI and the performed measurements. After consulting with the traffic managers the average unloading time for trucks is set on 60 minutes both for self-loaders and logistic partner users.

In Table 4.7 the outcomes of the real data and the simulated data is shown. The difference between the real data and the simulated trailer data is relatively small. The difference within the truck data is larger. No real data on the unloading time of trucks was available. Therefore, an estimate was used, this could explain the larger difference. Another reason for the larger difference could be that the assumption on the truck load is not correct. If trucks in the simulation model have a larger load than in the real world this could explain the difference in unloading time. Since the unloading time is influenced by many assumptions and the real data used for comparison is an estimate, it is hard to say if the simulation outcomes differ too much.

The division north south also show some differences. The real data value is based on the total build-up and break-down days from the PLMA convention. However, the simulation works with day data. The arrival of trucks within the simulation is modelled with the real arrival data of that specific day. It could be that certain days show different patterns in the division of north and south. And that on the specific day used in the simulation the truck arrivals are more evenly divided compared to other days.

Table 4.7: Validation outcomes

	Real data value	Simulated value	Difference
Unloading time (min)			
Trailer SL	95	97,824	2,97%
Trailer LP	95	91,554	-3,63%
Truck SL	60	64,488	7,48%
Truck LP	60	65,616	9,36%
Share of trucks destination			
North	60,69%	54,84%	-9,64%
South	39,31%	45,16%	14,88%

The validation shows that the simulation model outcomes differ from the expected values. In general a simulation model is never 100% valid and the goal of such a model is mainly to imitate the behaviour of a system. The goal of this simulation model is to adjust it and see how different system designs influence the performance, space and negative external effects. The deviation between the expected values and simulated values can influence the outcomes of these simulations. However, the designs are all based on the model of the current situation and will therefore show the same deviations. This means that it is still possible to make a good comparison between the designs even though the outcomes might be deviating from the real values.

4.6 Conclusion

To answer sub-question 4 section 1.6: *"How does the current logistics system affect performance, nuisance and space?"* the data of the current system is analysed and a simulation model of the current system is made. With the simulation model the behaviour of the current system can be explored. The simulation model use the data of the current system. Where data is missing estimates were used in communication with RAI traffic managers.

The performance of the current system depends on the unloading times, waiting time and the delivery time. The analysis of the current data showed that trucks and trailers often take more time to unload than the maximum time that is given for this process. The unloading time for a trailer is around 94 minutes and for a truck 65 minutes. The simulation outputs showed that in the base scenario the maximum waiting time is 115 minutes. This means that an arriving trailer or truck had to wait 115 minutes before an unloading spot became available. An important influence on these high waiting times are the peaks in the arrival process. The delivery time is influenced by the moving speed within the hall and the distance. The analysed data showed that the speeds within the halls are below the maximum which is 5 km/h. A benefit of the current system is that trailers and trucks unload within close proximity to the hall where they need to deliver. This ensures that the distances to the final location within the hall are small. The average delivery time in the base scenario is 52 minutes. A factor which influences unloading, waiting and delivery is the amount of forklifts. Increasing the number of forklifts reduces unloading times, waiting times and delivery times. However, an increase in forklifts results in higher costs since more forklifts have to be rented and more staff is needed. In the base scenario 40 forklifts are used to unload logistic partner users.

In the current situation the neighbourhood faces considerable nuisance caused by all trucks and trailers that enter the RAI 61% unloads on the north side. This means that on a busy day hundreds of trucks and trailers unload at the north side. This causes visual and noise nuisance. Another impact that the simulation model showed is that trucks and trailers arriving at the north side sometimes have to wait before an unloading spot is available. In this case trucks and trailers have to wait on the north side, which can lead to waiting trucks and trailers in the neighbourhoods and on roads.

The space that is occupied by logistic processes in the current situation consists mainly of work sites. These work sites consists of unloading spots, which take up space. The work sites consist of 46 trailer spots and 58 trucks spots. In the current situation buffers are not necessary since the goods are directly transported into the hall where they are used or stored at the stand.

Overall it can be said that the current system can improve on performance mainly on unloading and waiting times. The benefit of the current system is that the unloading takes place close to the hall, which ensures low delivery times. Also, the costs of the current system are relatively low, the main costs are the rental of forklifts and the drivers. Around the RAI much space is occupied by unloading spots. However, buffer space is not needed since goods are directly transported to the final location.

Part IV

Design

5 | Logistic Design

In this chapter, several strategies and designs to improve inbound logistics will be explored. Before designing new logistics system the ideal situation and the requirements and constraints are defined. With the use of the literature study, requirements analysis and the data analysis in the prior chapter several strategies and new logistic designs are made. Three main strategies will be introduced. These strategies focus on controlling the arrival process and speeding up the unloading process. After researching these strategies the decision is made whether to incorporate them in the final designs or not. After this decision five different designs are introduced. These designs differ with regard to infrastructure and material handling equipment. The strategies and the different designs will be researched with the use of DES simulation models. The DES model introduced in chapter 4 will be used. This model will be adjusted to represent the new design.

5.1 Ideal Situation

In an ideal situation the logistics at the RAI would not cause nuisance to the neighbourhood, would not lead to long waiting times, disruptions and all trucks and trailers would unload within the given time frame or faster.

In an ideal situation the RAI would construct a warehouse close to Amsterdam near the highway. All trucks and trailers would deliver their goods to the warehouse. The goods are stored at the warehouse and transported to the RAI at the time when they are needed. For the transportation from the warehouse to the RAI electric trucks would be used. To reach this ideal situation the following steps should be taken.

At the RAI the north side should be entirely closed off for logistics. This means that trucks or trailers are no longer allowed to enter the north side. A tunnel should be constructed from the south side to the north side, which is used for the transportation to the north side. Besides constructing a new route the construction of unloading spots is also of importance. Since the north side is closed trucks and trailers should unload elsewhere. To reduce emissions and noise nuisance electric forklifts and EPTs should be used.

Besides adjusting infrastructure and constructing buildings and roads several other measures should be included. One of these measures is the implementation of a truck appointment system. With the help of a truck appointment system all information about incoming trucks and trailers is known beforehand. The warehouse knows the amount of trucks and trailers coming in and the goods they deliver. The truck appointment system also controls the arrival pattern of trucks and trailers. With the use of time-slots only a certain amount of trucks and trailers are allowed, which reduces peak behaviour and waiting times. Also, the operational time should be extended depending on the number of trucks and trailers. During busy days the operational time should be extended beyond the current 12 hours. This ensures a lower pressure on the logistics of the RAI.

Another measure is controlling the unloading process. In the current situation there are two types of unloading self-loaders and logistic partner users. To keep control of this process self-loaders could be prohibited. In this case all unloading is done by the logistic partner. When the logistic partner is responsible for all unloading they can optimise this process. This can, for example, be achieved by cross-docking. Forklifts take the pallet out of the truck and bring it to an buffer area where the pallet is then picked up by another vehicle and brought the final location within the hall.

In the ideal situation transportation from buffer to the stand in the hall would be done with the use of automated vehicles such as AGVs, RGVs or autonomous vehicles. With the use of these vehicle types efficiency can be improved since the driving is more precise and there is no risk of human errors being made. Besides the increase in efficiency the labour costs would be reduced since the vehicles drive automatically without human intervention. In order to work with these vehicles all goods should have a RFID tag. With the help of these tags the automated vehicles know where the goods should be delivered without human intervention.

The situation described above would reduce nuisance, waiting times and disruptions. It would also improve the unloading process. However, implementing automated vehicles at the RAI would be very difficult. The RAI has a very flexible environment, which changes for every convention. This means that paths and halls have a completely different lay-out for every convention. Besides the differing lay-out the situation within the halls is always very chaotic. There is always construction of stands going on and many people walk through these halls to ensure the build-up of the convention. Implementation of automated vehicles in such an environment is hardly possible since automated vehicles rely on obstacle free and sometimes predefined routes and cannot cope with obstacles well. The construction of buildings and tunnels is associated with high investment costs. The RAI has limited funds and therefore the investment costs should be reduced as much as possible.

The warehouse mentioned in the ideal situation will not be included in the further designs since this lies outside the scope of the research. However, it is important to mention that the implementation of a warehouse has benefits for the logistics at the RAI. Since the scope of this research focuses mainly on the logistic on the RAI site the design will only include the changes on the RAI site.

5.2 System Requirements

Two types of requirements will be distinguished: functional and non-functional requirements. Functional requirements explain what the system needs to be able to do. Non-functional requirements are used to judge the process quality. The requirements are obtained through interviews with different stakeholders. The stakeholders that were interviewed are the head of traffic management, traffic manager, planning manager, event manager, logistic partner. Through these interviews insights are gained into what the system should be able to do and the advantages and disadvantages of the current system.

From the interviews it became clear that the current system has one important main advantage which is flexibility. The logistics can be adjusted according to the type and size of the convention. For big conventions the buffer area is used and for smaller conventions vehicles are allowed to enter the RAI immediately. The use of the buffer where trucks and trailers have to wait until there is space at the RAI has proved to be successful. Besides meeting the requirements the new design of the system should also comply with the constraints. The following requirements and constraints are based on the interviews and literature:

Functional requirements:

- The system should be flexible and able to handle changes since different conventions require different setups
- The system should be able to share information between different stakeholders such as arrivals of trucks and trailers and destination of loads
- The system should be able to reduce the peak-behaviour of arriving trucks and trailers
- The system should be able to serve vehicles immediately when they arrive within the planned time-slot
- The system should be able to unload trucks and trailers within the given time. Trailers should be unloaded within 60 minutes and trucks within 45 minutes

Non-functional requirements:

- The system should reduce nuisance for the neighbourhood
- The amount of commercial space should remain the same; however, it may be redistributed if this improves the loading/unloading process
- The system should maintain or improve the overall safety at the RAI

Constraints:

- Logistic processes must be executed at the RAI site
- Horizontal expansion of the site is practically impossible
- Entering the RAI on the north-side is only allowed in exceptional situations

5.3 Strategies to Regulate Inbound Logistics

During the design process it became clear that there are strategies that can influence the logistics in a positive way and improve the performance of the logistics system. To check how these strategies affect the performance an experiment was performed (Appendix G). If the effects are positive on the logistics system the decision is made to incorporate these strategies within the designs. The following strategies have been researched:

- Truck Appointment System: is used in order to control the arrivals of trucks and trailers. Now the trucks and trailers arrive whenever the driver wants. With the use of a truck appointment system only a limited amount of trucks and trailers are allowed within a certain time-slot
- Operational time: the time the RAI is open for logistics
- Cross-docking: instead of unloading a pallet and bringing it all the way to the hall with the same vehicle the process is split into two parts. First, a forklifts unloads a pallet and brings it to a buffer space nearby. Then an EPT or other vehicle picks up the pallet from the buffer and transports it to the final location within the hall

To research these general changes they are implemented within the current simulation model. The outcomes are checked in order to determine if they have the expected effect. The effect on the average unloading times and average waiting times are researched. With the use of a truck appointment system lower waiting times are expected since trucks and trailers arrive in smaller groups and peak-behaviour is reduced. The expected effect of extending the operational time is also lower waiting times since the trucks and trailers are spread out more over the day. This means that fewer trucks and trailers arrive on the same time-slot. The operational time has a direct effect on the truck appointment system. If there are more operational hours there are also more time-slots available. Finally, with the use of cross-docking a decrease in the unloading times of trucks and trailers is expected. Forklifts drive shorter distances before they are available to pick-up the next pallet. This decrease in unloading time is only expected for trucks and trailers that unload with the help of the logistic partner since self-loaders unload without the use of forklifts.

5.3.1 Truck Appointment System & Operational Time

To see the effect of the truck appointment system and operational time several runs are performed within the simulation model of the current situation. The truck appointment system has two options: time-slots per hour or time-slots per 15 minutes. For the operational time three options are tested: an operational time of 12 hours, 14 hours or 16 hours. Besides the different options for the truck appointment system and operational time the amount of trucks and trailers is also variable. There are three variations: a normal day, which has 160 trucks and trailers, a busy day, which has 280 trucks and trailers, and a very busy day, which has 400 trucks and trailers. The outcomes of the day with 400 trucks are shown in Table 5.1. The outcomes of the other scenarios can be seen in Appendix H.

Table 5.1: Truck Appointment System & Operational time: 400 trucks & trailers

	Operational time (hours)	Unloading time (min)				Waiting time (min)
		Trailer SL	Trailer LP	Truck SL	Truck LP	
Base		98	92	65	53	82.6
Time-slot						
Hour	12	101	95	65	68	33.1
15 Minutes	12	101	89	65	61	32.4
Hour	14	99	82	64	52	15.5
15 Minutes	14	99	79	64	49	11.1
Hour	16	97	72	64	48	5.7
15 Minutes	16	98	69	64	45	2.8

The outcomes show that implementing a truck appointment system with both one-hour time-slots and 15-minute time-slots has a positive effect on unloading and waiting times. As expected the effect on unloading times is only there for the trucks and trailers that use the services of the logistic partner to unload. If there are large peaks in the arrivals of trucks and trailers the forklifts have to handle a large number of trucks and trailers at the same time. When a truck appointment system is implemented an even spread of arriving trucks and trailers is established during the day. This spreads out the arrival peaks, which ensures that forklifts have to handle less trucks and trailers at the same time. Increasing the operational times also has an effect on unloading times and waiting times. By increasing operational times the amount of trucks and trailers arriving at a certain time-slot decreases, this leads to faster unloading times since forklifts have less trucks and trailers at the same time. The waiting times also decrease since the arrivals are spread out which means that there is less chance to exceed the available capacity. The effect of the truck appointment system and extending operational times is more pronounced during very busy days. During calm days small improvements are seen in unloading and waiting times, the busier the day, the more improvements can be seen.

Overall, taking into account the outputs, it can be concluded that a truck appointment system improves the waiting time and unloading times when comparing it to the base scenario. Busy days require even more control in order to reduce waiting times and unloading times. These reductions can be established with the use of longer operational times and smaller time-slots. On calmer days less control is needed, so larger time-slots can be used and extending operation times is not necessary.

The decision is made to only include the 15-minute time-slots in the further designs. This decision was prompted by the positive effect these shorter time-slots have on unloading and waiting times during busy days. Another aspect that influenced this decision is the fact that arriving trucks and trailers have to register at the work site. These registration queues will be smaller when 15 minutes time-slots are used. For the operational time the 12 hour and 16 hour options will be included since they represent the best and worst option.

5.3.2 Cross-docking

To check the effect of cross-docking the simulation model was adjusted to a cross-docking situation. This means that forklifts pick up the pallets from the truck or trailer, which use the logistic partner, and bring them to a buffer. From the buffer the pallets are transported with EPTs to the final location within the hall. To check the effect four scenarios and a base situation are introduced. The scenarios differ with regard to the amount of forklifts and EPTs, as can be seen in Table 5.2. When cross-docking is used every work site needs its own buffer space. To determine how much buffer space is needed, the maximum number of pallets within the buffer is checked for every scenario. The amount of arriving trucks and trailers within the scenarios is set on 280, this represents a busy day. In Table 5.2 the cross-dock scenarios and their outcomes are shown.

In the base scenario 40 forklifts are used. The outcomes show that if the same amount of forklifts are used and 20 EPTs are added the unloading times are reduced with almost 50%. The unloading times only reduce for the logistic partner users since they use the forklifts. Self-loaders do not use forklifts and are therefore not influenced by cross-docking. When only 20 forklifts are used the unloading times increase. However, the average waiting time decreases compared to the base scenario. A reason for this could be the distribution of forklifts over the work sites. If a busy work site has many forklifts assigned to it the unloading times at this specific work site will decrease, which also leads to a decrease in waiting times. However, other work sites that have less forklifts assigned to them will show longer unloading times. If these work sites have a large unused capacity these longer unloading times will not immediately lead to longer waiting times since there are still sufficient available unloading spots. For the buffer space the number of EPTs is of importance. Using less EPTs results in more pallets in the buffer. There is a relation between forklifts and EPTs. If there are many forklifts in use the unloading process of trucks and trailers is fast. This means that pallets enter the buffer rapidly one after the other. If there are not enough EPTs they cannot keep up with the inflow of pallets which results in a high number of pallets in the buffer. The maximum number of pallets in the buffer occurred in the scenario with 40 forklifts and 20 EPTs. The exact number of pallets in the buffer for every work site can be found in Appendix H

Table 5.2: Effects of cross-docking: 280 truck & trailers

	# Forklifts	# EPTs	Unloading time (min) Trailer SL	Trailer LP	Truck SL	Truck LP	Waiting time (min)	# Pallets in buffer
Base	40	0	98	92	64	66	16.9	0
Cross-dock	40	20	99	51	65	33	2.5	848
Cross-dock	20	20	99	93	64	90	6.0	543
Cross-dock	40	40	101	50	65	33	2.4	357
Cross-dock	20	40	100	91	65	88	5.5	34

To see the combined effect of cross-docking, a truck appointment system and extending operational time, these situations are also tested. The outcomes, Table 5.3, show that combining these three strategies improves unloading and waiting times even further. For the comparison the scenario with 15 minute time-slots is used and an operational time of 16 hours, which is the best case scenario. A better spread of trucks and trailers over the day ensures a more constant environment. With only 20 forklifts the unloading times are similar to the results with 40 forklifts without the truck appointment system. When 40 forklifts are used the unloading times decrease even further to 45 minutes for a trailer and only 30 minutes for a truck. Besides reducing the unloading times, the number of pallets in the buffer also decreases. The waiting times are reduced to 0, which is much lower compared to the waiting times of the cross-docking only. The required buffer space in the worst case scenario decreased from 848 to 348. The exact division of the required buffer space for every work site can be found in Appendix H. A combination of a truck appointment system, extended operational times and cross-docking can ensure lower unloading and waiting times. Cross-docking operates better when combined with a truck appointment system since forklifts can operate under constant circumstances, which means no peak of trucks and trailers.

Table 5.3: Combined effects of cross-docking and truck appointment system, operational time 16 hours: 280 trucks & trailers

# Forklifts	# EPTS	Unloading time (min) Trailer SL	Trailer LP	Truck SL	Truck LP	Waiting time (min)	# Pallets in buffer
40	20	99	45	64	31	0	348
20	20	101	53	64	40	0	255
40	40	97	45	64	29	0	131
20	40	98	52	64	39	0	31

Based on these outcomes the decision was made to incorporate all three strategies in the new designs. The outcomes showed that these strategies reduce waiting and unloading times and can reduce the required buffer space. However, these strategies do not reduce the nuisance and they reduce other logistic space. As mentioned before, the RAI wants to close off the north side and relocate logistics to the south side. In order to do this severe changes need to be made to the logistic infrastructure. These changes are implemented in the different designs.

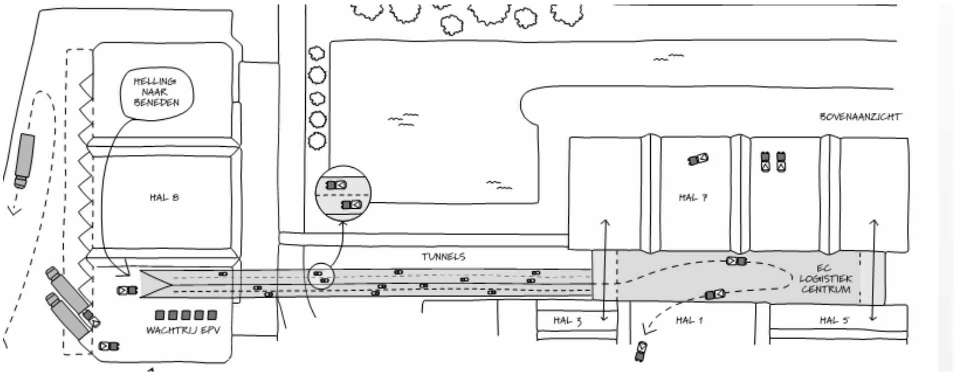
5.4 Design Alternatives

In cooperation with the RAI different designs were developed. Two main designs (design 1 and design 2) were proposed by the RAI for this research. The other 3 designs are based on ideas found in literature. The 3 designs are based on design 1; however, they use different material handling equipment.

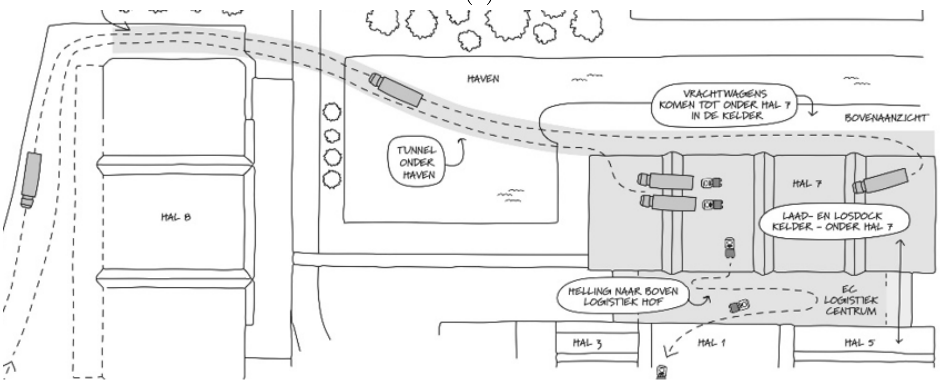
The main goal of the new design is to reduce nuisance on the north side. Therefore the decision is made to handle all logistics on the south side. This means that the work sites (P8, P9 and P10) on the north side will no longer be available for logistic purposes. Space on the south side is limited, consequently it is not possible to create as many unloading spots as before. In the current situation the P8, P9 and P10 have 18 unloading spots for trucks and 29 for trailers in total. With information from the RAI and with the help of an architect it was estimated that the space at the south side of the RAI can fit 7 trailer and 6 truck unloading spots. A second option is to move logistics underground at the north side. A logistic center would be constructed underground under hall 7 and has a similar capacity for trucks and trailers as the first option. The new location for the north side logistics center will be called New Logistics North (NLN). For both options the construction of a tunnel from the south side to the north side is necessary. The work sites P5A and P5B will remain the same. The work sites of the P5A and P5B are elevated, which means that the NLN on the south side can be partly constructed underneath it.

Another important aspect is that self-unloading your truck or trailer will no longer be allowed in the new designs. Since self-loaders are only allowed to use non-motorized equipment, the transportation of goods from the south side to the north side would take a very long time. Due to the reduction in the capacity of unloading spots it is not possible to allow these long unloading times. Since the P5A and P5B do not use the tunnel, a decision could be made to allow self-loaders that deliver to the halls on the south side. However, it would be hard to justify to stand builders in the north complex why they cannot self-load if the stand builders on the south side are still allowed to do this. Abolishing self-loaders could lead to serious problems since the transporters might be unhappy about this. Therefore, it should be considered how to implement this decision and who is going to pay for the unloading of the trucks and trailers. All five design alternatives use the same processes for the unloading of trucks and trailers at the P5A and P5B. This will result in similar outcomes for unloading times and delivery times at the P5A and P5B. Therefore, most attention will be given to the outcomes of the NLN.

All proposed designs have certain similarities. These similarities are a truck appoint system, extended operational times, the use of cross-docking and the construction of a tunnel from the south to the north side. Together with RAI management and an architect different lay-outs for the tunnel have been explored. Two of the lay-outs seemed to be most feasible. These can be seen in Figure 5.1. The first option shows a straight tunnel from the south side, which ends between hall 7 and 6. This tunnel will only be used by small vehicles such as EPTs and forklifts. The second option shows a tunnel, which ends underneath hall 7. This tunnel will be used by trucks and trailers. Besides the difference in route the tunnels also differ in size. Option 1 consists of two tunnels with the following measurements: 5 meters wide and 3 meters high. Option 2 consists of one larger tunnel with the following measurements: a width of 7 meters and a height of 4.5 meters (*Afweging opties logistiek RAI terrein*, 23-01-2020).



(a)



(b)

Figure 5.1: (a) Tunnel option 1 (b) Tunnel option 2

To be able to compare the designs in a fair way, a fixed number of forklifts and EPTs will be set, which will be kept constant over all designs. Having a variable number of forklifts and EPTs affects unloading, waiting and delivery times, which would make it very difficult to compare the designs. This was shown in the simulation model of the current situation. To see how the designs behave an experiment is used. This experiment consists of different scenarios, which differ with regard to the number of arriving trucks and trailers and operational time (Appendix G).

5.4.1 Design 1: Everything on South Side

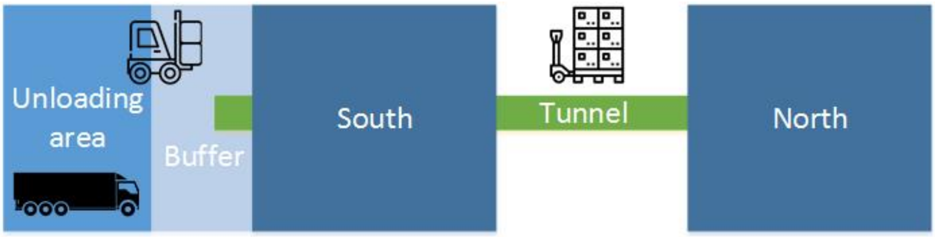


Figure 5.2: Design 1

Within this design the NLN is constructed at the south side. All logistics from the north side is now handled at the NLN. In Figure 5.2 a simplified overview is given. This design uses tunnel layout 1.

At the unloading area trucks will be unloaded with the use of forklifts. The forklifts bring the pallets to a buffer where the pallets can be temporarily stored. At the buffer the pallets are picked up with EPTs and brought to their final location on the north side. Transportation to the north side is provided by a tunnel constructed underneath the RAI. As soon as the EPT has delivered the pallet it goes back to pick-up the next pallet. The EPTs are humanly controlled by drivers. In Appendix I the conceptual models of the different designs can be seen. Figure I.1 shows the conceptual model of design 1.

An advantage of this design is that it is highly flexible and not vulnerable to technical defects. The number of EPTs can be adjusted to the expected workload of a particular day. In case of a technical defect, such as a EPT that breaks down, there is little impact on the other EPTs. If the EPT would break-down within the tunnel this could hinder the other EPTs. However, it would not stop the logistic operation. Another advantage is that the tunnel can be used by other vehicles and that different types of goods can be transported. This means that the system is not only limited to goods on pallets. A disadvantage of this design is that the EPTs have to drive a long distance from the south side to the north side. If the distances are longer this means the EPTs take more time to make the delivery. To keep up with the unloaded pallets a large number of EPTs is required. If the EPTs cannot keep up with the pallets that are being delivered the pallets will pile up in the buffer area. Storing a large number of pallets within the buffer means that more space is needed or the buffer becomes congested and slows down the process.

5.4.2 Design 2: Underground Logistics Center on North Side

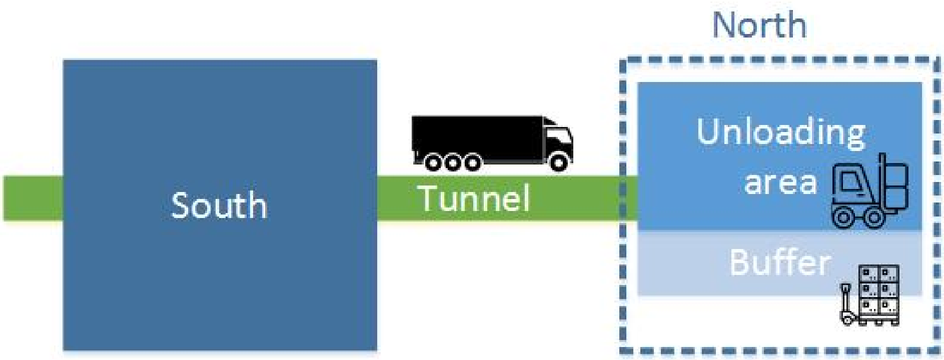


Figure 5.3: Design 2

The second design keeps the logistics on the north side. However, these logistics are taking place underground. The capacity underground is similar to the capacity on the south side, which consists of 7 trailer and 6 truck unloading spots. Trucks and trailers enter the RAI site via the south side where they drive through a tunnel to the north side, the tunnel follows tunnel option 2. The tunnel leads to the NLN, which is constructed underneath hall 7 on the north side.

At this logistic center a similar unloading process takes place as in design 1. Trucks and trailers are unloaded with forklifts and the forklifts bring the pallets to a buffer. At the buffer the pallets are picked up and brought to the final destination within the hall by EPTs, which are humanly controlled. An overview of the conceptual model can be found in Figure I.2.

One of the advantages of this design is that it shortens the delivery distances driven by the EPTs. Goods are unloaded at the north side where they need to be. It also has a high flexibility such as design 1. However, there are also some disadvantages such as: vulnerability to vehicle breakdowns and high costs. The vulnerability is higher than in design 1 since trucks and trailers drive through the tunnel. If a truck or trailer would break down within the tunnel this would stop the logistic process. It would be hard to let other trucks or trailers pass the stranded vehicle. Also, the costs of this design are much higher since the logistic center has to be constructed underneath the RAI and the tunnels need to be larger. Also, the tunnels would have to comply with more rules and regulations since trucks and trailers are driving through them instead of smaller vehicles.

5.4.3 Design 3: Conveyor Belt through Tunnel

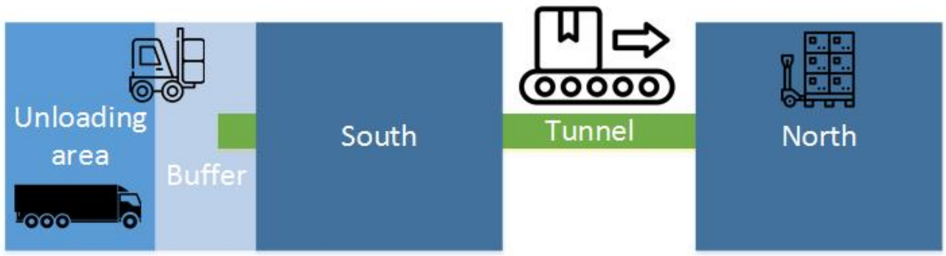


Figure 5.4: Design 3

This design has the same set-up for the NLN and tunnel as design 1. The transportation to the north side is partially done with EPTs and partly by means of a conveyor belt. Through the tunnels conveyor belts will be used for the transportation of goods through the tunnels.

Incoming trucks and trailers are unloaded with forklifts at the south side. The forklifts bring the goods to a buffer area. At this buffer area the goods are picked up by another forklift, which places them on the conveyor belt. The decision is made to implement two conveyors since one would not be sufficient. The conveyors will be bidirectional. This means that during build-up they run from south to north and during breakdown from north to south. The goods are transported with the conveyor to the north side. At the north side a forklift unloads the goods from the conveyor and places them in a buffer area. At this buffer area the goods are picked up by an EPT and are brought to the final location. The conceptual model of this design can be found in Figure I.3

The advantage of this system is that it reduces the delivery distances of the EPTs on the north side. The conveyor can also be seen as a buffer since the pallets are stored on the conveyor. This could mean that the buffer on the south side could be smaller since fewer goods are stored in the buffer. Most conveyors are also capable of handling goods that are not delivered on pallets. The loading and unloading process for these goods would be different and could be more time-consuming than putting pallets on the conveyor. One disadvantage of this system is the low flexibility. If conveyors are installed within the tunnel there is no other option for transportation through the tunnel. This means that if the conveyors have technical issues or maintenance is taking place the whole logistic process from the south side to the north side stops. Furthermore, it is not possible to transport products that do not fit on the conveyor to the other side through the tunnel since the conveyors are taking up the space here.

5.4.4 Design 4: Rail Guided Vehicles through Tunnel

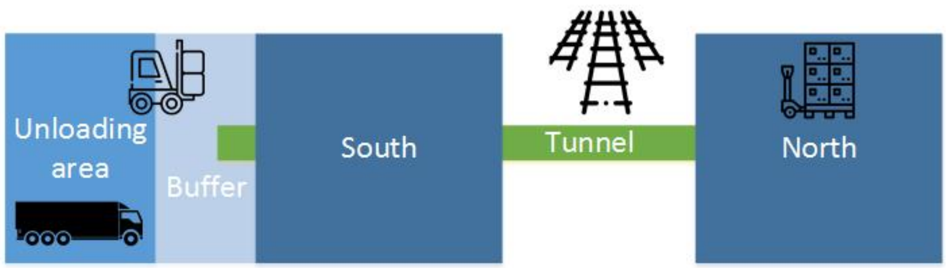


Figure 5.5: Design 4

Design 4 also has the same set-up for the NLN and tunnel as design 1. The transportation from the south side is partially done with rail guided vehicles (RGVs) and partly with EPTs. Within the tunnel a rail guided system will be installed.

The trucks and trailers are unloaded with forklifts. The goods are transported to the RGV dock, this dock consists of 4 small conveyors that are used to automatically load the RGV. The forklift puts the goods on the conveyor and can immediately return to the truck or trailer to continue the unloading. The RGV drives to the dock to pick up the goods and transports them to the unloading docks at the south side. Here there are also 4 small conveyors that are used to automatically unload the RGV. EPTs are used on the north side to pick up the goods from the conveyors and to transport them to the right stand. The conceptual model of this design can be seen in Figure I.4

Advantages of this system are the reduction of the delivery distances of the EPTs and the automatic loading process of the RGVs. The RGVs also have a high transportation speed compared to a conveyor or AGVs. Depending on the expected load that has to be handled, the number of RGVs can be adjusted. Different types of RGVs exist with their own characteristics. Most RGVs are capable of transferring heavy loads up to 20 tons and loads that are not delivered on pallets. However, these loads have to be fixed on a plate, which is time consuming. The rail that is used can either be constructed above the floor or within the floor. If the rail is constructed within the floor it is still possible to drive over the floor with EPTs or other vehicles. A disadvantage of this system is the vulnerability of a system break-down. The automated loading and unloading process of the RGVs makes use of many mechanical parts and in case of a break-down this would stop the entire RGV system. If a RGV breaks down it can easily be taken out of the system for reparation. The choice of the RGV and rail type influences the flexibility of the system. However, a more flexible system would also entail higher costs due to a more expensive infrastructure.

5.4.5 Design 5: Automated Vehicles through Tunnel

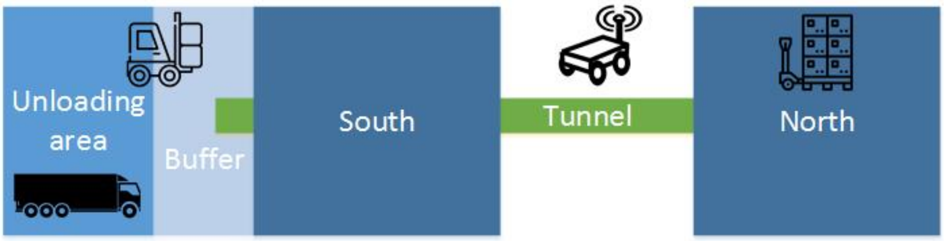


Figure 5.6: Design 5

Design 5 has the same set-up for the NLN and tunnel as design 1. All vehicles unload on the south side and are unloaded with forklifts. Instead of transporting the goods with RGVs the transportation will be done with AGVs or autonomous vehicles. These vehicles do not require a rail since they can drive on their own and use lasers, markings or their own sensors to guide them. These vehicles are used for floor-to-floor transportation. This means that the pallets can be picked up from the floor and can be put back on the floor by the AGV.

The forklift that unloads the pallet from the truck or trailers takes it to the AGV docks. The pallets are put down in a marked area, which is on floor level. The AGV can drive to the marked area and pick up the pallet. The pallet is transported to the north side and is put in dock. EPTs pick up the pallets from the dock at the north side and bring them to the final location in the hall. An overview of the conceptual model of design 5 can be found in Figure I.5

This system has similar advantages as design 4. It shortens the distance driven by EPTs and the AGVs should be able to load and unload the pallets automatically. This design is more flexible than design 4 since the infrastructure required for AGVs can also easily be used by other vehicles. In case of a system failure it is possible to keep transporting goods from south to north with the use of normal EPTs. At the moment it is hard to implement AGVs throughout the entire RAI. This is the case since the path-layout in the halls changes for every convention and during build-up builders and obstacles occupy the paths. AGVs are not yet able to handle these situations. However, in the future this could be possible. In the future the AGV network of this design could be expanded into the halls. However, working with AGVs also has some disadvantages. Pallet moving AGVs can only move goods that are fixed on a pallet. If goods are not delivered on pallets they have to be transported manually or they should be fixed on a pallet first. Also, the weight that can be transported by AGV ranges from 1 to 3 tons, which is less than for RGVs or EPTs.

Both AGVs or autonomous vehicles could be implemented. The advantage of AGVs is that they are often implemented in warehouses and much is known about these vehicles and how they function. The technology of autonomous vehicles is more recent and less implemented. However, the technology looks very promising for the future. If these vehicles are able to avoid obstacles as well as expected implementation within the halls could be possible. Within the simulation model AGVs are implemented since they travel over a predefined path. However, the outcomes will not differ that much for autonomous vehicles. The infrastructure within the tunnel is very basic, which would not lead to massive difference in the results.

A visualization of how the designs are modeled within the simulation program can be seen in Appendix J

5.5 Design Parameters

The simulation models of the designs need certain parameters values to be able to run. Most of these parameters are determined by data analysed in section 4.1. These parameters are forklift and EPT speeds, unloading times and registration time. The designs are partly similar to the current situation therefore certain parameters can remain the same as the parameters in the simulation models of the current situation. However, there are also significant differences between the designs and the current situation. For this reason, new parameters are added and certain parameters are adjusted. An overview of the parameters can be found in Appendix E.

The number of forklifts and EPTs are fixed for every design alternative. This decision was made to be able to compare the alternatives in a fair way. Adding forklifts or EPTs to a certain design would have a positive effect on delivery times and unloading times. To determine the maximum number of forklifts and EPTs, design 1 is used since this design is expected to use the largest number of EPTs. The expectation is that the influence of the number of forklifts has a similar effect on all designs since the unloading processes of trucks and trailers are similar. To determine the number of forklifts required the influence on unloading times and waiting times is checked. To determine the number of EPTs, the influence on the buffer size is checked.

The scenarios were run with the data set, which represents a standard busy situation. This means that 280 trucks and trailers arrived within an operational time of 12 hours. The arrival process was peak shaved with time-slots of 15 minutes.

5.5.1 Number of Forklifts

To check the effect of the number of forklifts on unloading times several runs were performed where the number of forklifts was increased in every run. The outcomes of these runs can be seen in Table 5.4. The outcomes are split for two areas which are the NLN and the P5 (P5A and P5B combined). The maximum allowed unloading time at the RAI is 45 minutes for a truck and 60 minutes for a trailer.

At the P5 it shows that with the use of 6 forklifts the average unloading times are shorter than the maximum allowed time. It also shows that by increasing the number of forklifts above 6, only a small reduction of the unloading times is seen. When the effect on waiting times is checked we see that the P5 has almost no waiting times. The decision was made to set the number of forklifts on the P5A and P5B on 6.

At the NLN using 15 forklifts ensures that the unloading times are beneath the maximum allowed unloading time. It also shows that after increasing the amount of forklifts to more than 15 hardly any changes occur in the unloading times and waiting times. Increasing the number of forklifts will reduce the waiting times as well. However, increasing the number of forklifts to more than 15 does not reduce these waiting times any further. Therefore, the decision was made to set the number of forklifts on the NLN on 15.

Table 5.4: Effect number of forklifts

Unloading times P5							Unloading times NLN						
Number of forklifts		3	6	9	12	15	Number of forklifts		5	10	15	20	25
P5A	Truck	215	36	32	31	31	P1	Truck	97	49	32	31	31
	Trailer	208	51	48	46	48		Trailer	147	68	48	48	48
P5B	Truck	120	31	29	29	29							
	Trailer	165	51	48	46	48							
Waiting times P5							Waiting times NLN						
P5	Truck/Trailer	1	1	1	1	1	P1	Truck	269	23	1	0	0
								Trailer	233	15	1	1	1

5.5.2 Number of EPTs

The effect of the number of EPTs on the amount of pallets in the buffer is shown in Table 5.5. Seven different scenario are run with an increasing number of EPTs. The used number of forklifts is fixed and set to the numbers mentioned above. The maximum number of pallets is the maximum number found in one of the simulation runs. The average is the average number of pallets in the buffer over all simulation runs. If the buffer contains a large amount of pallets much space is needed to store these pallets. The amount of pallets in the buffer increases if the EPTs are not able to keep up with the incoming pallets from the trucks and trailers. The buffer can be seen as a queue where pallets wait to be delivered. There are several options to solve a queue, such as increasing the amount of servers. In this case the EPTs can be seen as servers. An increase will lead to a decrease in the waiting queue. A balance has to be found between the queue size and the number of EPTs. If the queue size increases more space is required and if the number of EPTs is increased the costs will rise.

After analysing the results of the simulation runs the decision was made to set the number of EPTs at the P5A and P5B on 9. On the P5A a maximum buffer space of 71 pallets is required with 9 EPTs. However, the average buffer space during the simulations was only 11. Increasing the number of EPTs to 12 would reduce the maximum required buffer space to 17. However, the P5A has room to create a buffer with more capacity. The P5B has less room for a buffer therefore the decision was made to use 9 EPTs as well, which results in a buffer with a maximum of 14 pallets.

The number of pallets within the buffer on the NLN are much larger compared to the P5 buffer. This can be explained by the fact that the NLN has more incoming trucks and trailers to handle, which results in a higher inflow at the buffer. The EPTs also have to cover a large distance to transport pallets all the way to the north side, which is very time consuming. When only 10 EPTs are used, it shows that the buffer is at a certain point filled with almost 1400 pallets at a certain point. The decision was made to use 50 forklifts at the NLN the maximum buffer size is 130 pallets which seems doable. Increasing the number of EPTs even further to 60 will decrease the needed buffer space further. However, it will also increase the costs. Since the NLN has room for a buffer, the decision is made to set the amount of forklifts on 50.

Table 5.5: Effect number of EPTs

Pallets in buffer P5							
P5A (Number of EPTs)	3	6	9	12	15	18	21
Max	457	213	71	17	7	6	6
Average	282	88	11	2	1	1	1
P5B							
Max	287	64	14	5	5	5	5
Average	147	15	1	0	0	0	0
Pallets in buffer NLN							
NLN (number of EPTs)	10	20	30	40	50	60	70
Max	1.328	996	675	374	129	45	15
Average	873	626	379	165	37	6	2

Three of the designs use other vehicle types besides the forklift and the EPTs mentioned above. Design alternative 3 uses forklifts to unload and load the conveyors, design 4 uses RGVs and design 5 uses AGVs. To determine the number of these vehicles a similar approach is used. The number of used vehicles can be found in Appendix E.

5.6 Simulation Results

To see how the different designs behave, several scenarios are run. These scenarios differ with regard to the amount of arriving vehicles and operational time. An overview of these scenarios can be found in Appendix G. These scenarios are a day with 160 arriving vehicles, a day with 280 vehicles and a day with 400 vehicles. Each of these days is run with the operational times of 12, 14 and 16 hours, which results in nine scenarios.

To evaluate the different designs the KPIs are used. The outcomes are the average unloading times, average waiting times, average delivery times, maximum needed buffer space, number of EPTs used and the number of other vehicles used. The buffer size is determined by the maximum number of pallets that were present within the buffers during the simulation runs. The total is calculated by adding up the maximum values from the different buffer locations. The number of used EPTs and forklifts at the NLN are set to the numbers determined by the simulation runs in the prior section. The use of other vehicles occur in design 3, design 4 and design 5. In design 3 the other vehicles are the forklifts that are used to load/unload pallets from the conveyor. In design 4 these vehicles represent the RGVs and in design 5 the AGVs. An overview of the inputs can be found in section 5.5.

In Table 5.7 the outcomes of the experiment are shown with an operational time of 12 hours and the arrival of 280 trucks. The arrival of the 280 trucks can be seen as a busy day, but not the busiest day the RAI has to handle. The operational time of 12 hours can be seen as the operational time in the current situation. The outcomes show that the unloading times are almost similar for all designs. This makes sense since they all use the same amount of forklifts for the unloading process therefore large differences in the outcomes were not expected. In Table 5.6 and Table 5.8 the outcomes are shown for the day with 160 and 400 trucks and trailers both with an operational time of 12 hours. In Table 5.9 the outcomes are shown for a day with 400 trucks and trailers and an operational time of 16 hours.

Table 5.6: Design outcomes 160 trucks and trailers. operational time 12 hours

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Design 1	30.9	48.2	30.5	45.1	30.3	46.5	0.0	0.0	31.1	27	41	0
Design 2	32.3	47.7	29.9	46.7	31.0	46.2	0.0	0.0	27.7	23	27	0
Design 3	31.8	48.3	30.0	46.8	31.1	46.3	0.0	0.0	47.0	53	18	6
Design 4	31.6	48.3	29.4	46.6	30.5	45.4	0.0	0.0	30.1	13	25	15
Design 5	31.8	46.8	29.7	46.1	30.6	45.7	0.0	0.0	31.3	12	26	22

Table 5.7: Design outcomes 280 trucks and trailers. operational time 12 hours

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Design 1	36.9	51.8	31.9	50.4	32.4	48.8	0.0	1.1	47.0	228	50	0
Design 2	36.6	52.4	31.7	48.9	33.8	49.3	0.0	7.3	29.9	54	34	0
Design 3	36.5	52.6	31.7	50.0	32.0	48.4	0.0	0.9	117.8	562	20	6
Design 4	36.9	51.5	32.1	50.2	32.0	47.4	0.0	0.6	32.1	61	32	18
Design 5	37.1	52.1	31.6	50.4	33.3	47.8	0.0	1.0	33.2	48	32	27

Table 5.8: Design outcomes 400 trucks and trailers. operational time 12 hours

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Design 1	59.8	84.6	30.9	49.5	34.4	54.0	0.0	83.4	135.4	876	50	0
Design 2	62.2	88.0	30.2	48.6	33.6	52.8	0.0	172.9	37.9	51	32	0
Design 3	56.8	80.3	30.1	47.6	34.0	53.2	0.0	79.1	185.6	1302	20	6
Design 4	56.5	81.9	30.6	47.8	34.8	53.2	0.0	88.3	41.4	54	33	19
Design 5	57.1	81.2	30.6	50.4	36.7	54.6	0.1	109.9	42.0	44	32	28

Table 5.9: Design outcomes 400 trucks and trailers. operational time 16 hours

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Design 1	33.0	51.3	30.3	47.8	32.4	48.7	0.0	2.4	94.3	597	50	0
Design 2	32.9	49.6	29.9	47.2	34.3	51.9	0.0	48.5	29.7	46	34	0
Design 3	33.0	51.1	30.1	48.1	32.3	48.9	0.0	2.2	155.9	1052	20	6
Design 4	33.4	50.9	29.8	46.9	32.2	47.6	0.0	1.8	31.6	37	34	18
Design 5	33.2	50.2	30.4	46.5	34.5	49.5	0.0	2.7	33.3	29	31	27

5.7 Conclusion

To be able to answer the sub-question: *Which logistics system designs can be implemented and how do they affect the performance, nuisance and space?* several designs have been developed. These designs contain several strategies to improve performance, reduce nuisance and space. The strategies that are included in the research are: a truck appointment system, extending operational time and cross-docking. Besides these strategies the designs differ with regard to infrastructure and material handling equipment to see how this affects the performance, nuisance and space. To see the effects of these designs, simulation models of all designs have been made and several scenarios are run. The performance is measured based on the KPIs, which are unloading time, delivery time, waiting time, needed space, number of vehicles, nuisance and costs.

A truck appointment system ensures that the arrival of trucks and trailers is evenly spread out during the day. This resulted in lower unloading and waiting times. Increasing the operational time reduces the amount of arriving trucks and trailers arriving at the same moment. This reduces unloading and waiting times even further. Cross-docking is a method to unload trucks and trailers with the use of a buffer. The use of cross-docking can decrease unloading times with almost 50%. However, to implement cross-docking buffer space is required to store pallets. To reduce buffer space cross-docking should be combined with peak-shaving and longer operational times.

The simulation outputs showed that the unloading times of trucks are similar for the different designs since the designs all included the same amount of forklifts and the same unloading method. Design 2 showed the longest waiting times for trucks and trailers compared to the other designs. This can be explained by the fact that in design 2 trucks and trailers wait at the south side, for a free unloading spot, before they can drive through the tunnel to the north side. Driving through the tunnel and parking on the spot takes several minutes. During this time the unloading spot is unoccupied, which reduces the capacity. In the other designs the trucks and trailers wait near the unloading spots and almost no time is lost when the unloading spot becomes available. Design 1 and 3 need the largest buffer areas, which requires space. The large buffers suggests that the EPTs or conveyor cannot keep up with the inflow of the pallets. These designs also have the highest delivery times. Design 1 is also the only design which uses all available EPTs, the other designs use 30 to 20 fewer EPTs. Designs 4 and 5 use a lot of other vehicles, EPTs and AGVs, for the transportation of the pallets. All designs show waiting times when 280 or 400 trucks and trailers come in. When 280 trucks and trailers arrive the waiting times are around 10 minutes. However, when 400 trucks and trailers arrive the waiting times increase. Especially if operational times are short (12 hours) the waiting times increase. Extending the operational times can reduce these waiting times, especially during very busy days.

All designs lead to a zero percent usage of the north side which means that no trucks or trailers use the current work sites on the north side. This means that there will be no nuisance to the neighbourhood with all five designs.

To determine which of the above designs is the most optimal the analytical hierarchy process will be used. In this process the KPI cost will also be included.

Part V

Evaluate

6 | Analytical Hierarchy Process

In this chapter sub-question 5 (section 1.6) will be answered. An analytical hierarchy process (AHP) will be used to determine which criteria are of importance to the RAI when deciding on a new logistic design. In order to do this the results of the simulation performed in chapter 5 will be used. First the pairwise comparison matrix will be determined. Based on this matrix the weights of the criteria can be determined. The criteria scores of the different designs are normalised and multiplied by the criteria weights, which results in a ranking.

6.1 Pairwise comparison

AHP is used to determine the weights of the criteria that influence the decision process. To assign weights to the criteria the problem owner is asked to perform a pairwise comparison. A pairwise comparison means that all criteria are compared to each other on a scale from 1 to 9 (Saaty, 1990). A 9 means extremely important and a 1 equally important. The value between 1 and 9 is assigned to the criterion which is found to be more important, the reciprocal value is given to the other criterion. Doing this for every criterion leads to a pairwise comparison matrix as shown in Table 6.1.

The criteria used in the AHP are based on the KPIs and one other important factor which came up during the requirement analysis. The criteria based on the KPIs are the unloading time, waiting time, delivery time, space, number of EPTs, nuisance and costs. During the requirement analysis it became apparent that the RAI needs a flexible logistics system, which is able to handle different types of goods and is less vulnerable to defects and interruptions. Since flexibility is hard to express in a numerical value, it is not included within the KPIs. However, it is included within the AHP. A benefit of AHP is that these kind of criteria can easily be included by performing a pairwise comparison between the alternatives. The included KPIs are numerical and follow a linear utility except for the costs. Normally costs can be expressed in a numerical value. However, estimating the costs for every single design is difficult since there are still many uncertainties about the tunnel designs. Therefore, it is difficult to estimate what the final costs would be for the construction of these tunnels. To include costs in the AHP the same method as used to determine the flexibility is used. In chapter 6 a more detailed explanation on the calculation of flexibility and cost scores is given.

To include multiple perspectives into the AHP the decision was made to include three employees. These employees are a traffic manager, the manager of the traffic department and the interim manager who is responsible for logistic projects at the RAI. These employees have different opinions on which criteria are of importance. Their individual pairwise comparison matrices are combined to determine the group weights. In Appendix L the individual pairwise comparison matrices can be found and in Table 6.1 the combined pairwise comparison matrix is shown. The combined pairwise comparison matrix and the weights are calculated with the help of an online AHP tool (Goepel, 2018). Saaty (1990) states that a matrix should only be accepted if the consistency ratio is below 0.1. The consistency ratio of the combined matrix is 0.026 and therefore this matrix and the calculated weights are acceptable.

Table 6.1: Combined pairwise comparison matrix

	Weight	Unloading time	Waiting time	Delivery time	Space	Costs	Number of EPTs	Flexibility	Nuisance
Unloading time	**0.076**	1.000	0.550	3.659	0.382	1.053	0.523	0.405	0.523
Waiting time	**0.100**	1.817	1.000	5.593	0.243	1.671	0.693	0.585	0.405
Delivery time	**0.028**	0.273	0.179	1.000	0.131	0.431	0.306	0.179	0.179
Space	**0.280**	2.621	4.121	7.612	1.000	2.327	3.271	1.651	2.268
Costs	**0.072**	0.950	0.598	2.321	0.430	1.000	0.523	0.570	0.306
Number of EPTs	**0.129**	1.913	1.442	3.271	0.306	1.913	1.000	1.126	1.000
Flexibility	**0.153**	2.466	1.710	5.593	0.606	1.754	0.888	1.000	1.119
Nuisance	**0.162**	1.913	2.466	5.593	0.441	3.271	1.000	0.894	1.000

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The weights show which criteria are seem most important. A high weight indicates that the criterion is considered to be important and a low weight indicates it is considered less important. In this case space, nuisance and flexibility are considered to be the most important criteria. Delivery time, costs and unloading time are deemed the least important criteria.

6.2 Normalised Data

To be able to include the outcomes of the simulation model the data should be normalized. This normalization is done by dividing the criteria value by the sum of the criteria values. Since most values are considered to be positive when they are low, for example a lower unloading time is preferred, the multiplicative inverse is used. This leads to a high score for a low value. Several scenarios were run within the simulation model and these scenarios all have a different data output. The data is normalized for the scenarios that seem most important. These scenarios are 160 vehicles, 280 and 400 with an operational time of 12 hours, and 400 vehicles with an operation time of 16 hours.

For most criteria the data which is normalised are the numerical outputs of the simulation model. However, for the criteria space, costs and flexibility a different approach is used. The space is expressed in the amount of space required for the number of unloading spots and the required buffer space. The space required for the number of unloading spots is calculated by the number of full trailer spots, whereby two truck spots fit in one trailer spot, times the required surface. This surface is calculated to be 19 meters long and 4 meters wide . The buffer space is calculated by multiplying the amount of pallets within the buffer by the surface of a pallet. For the surface of the pallet the measurements of a standard euro pallet are used. These two numbers are summed up to represent the space needed. For flexibility and costs the same method is used. For both criteria a pairwise comparison matrix is made based on the estimation of the flexibility and costs of the design. These matrices can be found in Appendix L.

In Table 6.2 the normalised data is shown for the scenario with 280 vehicles and an operational time of 12 hours. The criteria all have a value between 0 and 1 and a larger value is desirable. In Appendix L the normalized data for the other scenarios are shown.

Table 6.2: Normalised data: 280 vehicles, operational time 12 hours

	Unloading times	Waiting times	Delivery times	Space	Number of EPTs & Forklifts	Flexibility	Nuisance	Costs
Current	0.095	0.012	0.135	0.116	0.233	0.425	0.001	0.423
Design 1	0.181	0.177	0.148	0.175	0.121	0.191	0.200	0.273
Design 2	0.180	0.028	0.232	0.183	0.153	0.191	0.200	0.029
Design 3	0.181	0.216	0.059	0.161	0.176	0.037	0.200	0.123
Design 4	0.182	0.357	0.217	0.182	0.158	0.078	0.200	0.050
Design 5	0.181	0.210	0.209	0.183	0.158	0.078	0.200	0.102

6.3 Ranking of the Designs

After normalizing the data the weighted score of the different designs can be calculated. This is done by multiplying the normalized data with the weight of the criteria. With these weighted scores the designs can be ranked. The highest score will have the highest rank and the lowest weighted score the lowest rank. In Table 6.3 the weighted scores and the ranking of the designs can be found for the scenario with 280 vehicles and an operational time of 12 hours. The weighted scores and ranking of the other scenario can be found in Appendix L.

A short recap of the designs will be given. Design 1 uses EPTs to transport the goods from the south side to the north side through the tunnel. Trucks and trailers unload at the south side. In Design 2 trucks and trailers drive through a tunnel from the south side to the north side. A logistic center is constructed underneath hall 7. Here the trucks and trailers are unloaded and the goods are brought to the stands with EPTs. In design 3, 4 and 5 trucks and trailers unload at the south side. Design 3 uses two conveyors to transport goods through the tunnel, design 4 uses RGVs and design 5 AGVs. After being transported through the tunnel the goods are picked up by EPTs and brought to the stand.

Table 6.3: Normalised data: 280 vehicles, operational time 12 hours

	Unloading times	Waiting times	Delivery times	Space	Number of EPTs & forklifts	Flexibility	Nuisance	Costs	Weighted score	**Rank**
Current	0.095	0.012	0.135	0.116	0.233	0.425	0.001	0.423	0.170	**3**
Design 1	0.181	0.177	0.148	0.175	0.121	0.191	0.200	0.273	0.181	**1**
Design 2	0.180	0.028	0.232	0.183	0.153	0.191	0.200	0.029	0.158	**5**
Design 3	0.181	0.216	0.059	0.161	0.176	0.037	0.200	0.123	0.152	**6**
Design 4	0.182	0.357	0.217	0.182	0.158	0.078	0.200	0.050	0.175	**2**
Design 5	0.181	0.210	0.209	0.183	0.158	0.078	0.200	0.102	0.164	**4**

In this scenario design 1 has the highest weighted score, followed by design 4 and the current design. Design 1 is ranked the highest, it reduces nuisance just as much as the other designs while it has lower costs. It also ensures fast unloading and short waiting times. However, it is not as flexible as the current design, but it is still the most flexible of the other design options. Design 1 uses the most EPTs and scores the lowest on this criterion. The current design scores well on flexibility and costs. However, it does not decrease the nuisance at all and it has a poor performance on waiting and unloading times. It also takes up a a considerable amount of space since in the current design more space is obtained by unloading spots. Design 3 is the worst-performing design due to long delivery times and a low flexibility. Designs 4 and 5 have a low score on flexibility as well since it will be harder to handle all types of goods and handle disruptions. Design 4 is ranked higher than design 5 since it has a better performance on waiting and delivery times. Design 2 suffers from long waiting times and high costs, which leads to a low-ranking position. For this scenario design 1 seems to be the best option, followed by design 4.

To check if the designs are also able to handle busier and calmer days, multiple scenarios were run. The outcomes of these scenarios can be seen in Appendix L. An overview of the design rankings of these scenarios can be seen in Figure 6.1. During a calmer day with 160 trucks and trailers design 1 is also ranked as the best, followed by design 2 and the current design. Design 3 is the lowest-ranked scenario. In a busy scenario with 400 trucks and trailers and an operational time of 12 hours design 1 is not the best-ranked design anymore. In this scenario the current design scores best. The reason for this is that the waiting times in the other designs increased. The current design has more capacity since it has more unloading spots. The other design alternatives have less capacity and since the operational time is only 12 hours, the waiting times increased in these designs. Design 1 is still ranked as the second best option. The scenario with 400 vehicles and an operational time of 16 hours shows a different ranking. Design 1 is ranked highest, followed by the current design and design 4.

There are differences in the rankings and scores of the designs. However, these differences are small, which means that there is no design that clearly stands out as the best option. It can be said that design 3 is the least preferable design since is scored lowest on all 4 scenarios. The other scenarios score higher and the rankings differ for every scenario. Design 1 is a preferable option since it has high flexibility and low costs. However, it uses a considerable amount of buffer space. Within the AHP space is defined as the space needed for unloading spots and the space needed for pallets. The space for the amount of unloading spots is the same for all designs, except for the current situation. The buffer space differs for every design and is only a small part of the total space required. Therefore, the scores on space for the five new designs only differ slightly from each other. This could mean that the needed buffer space is underestimated in the scoring.

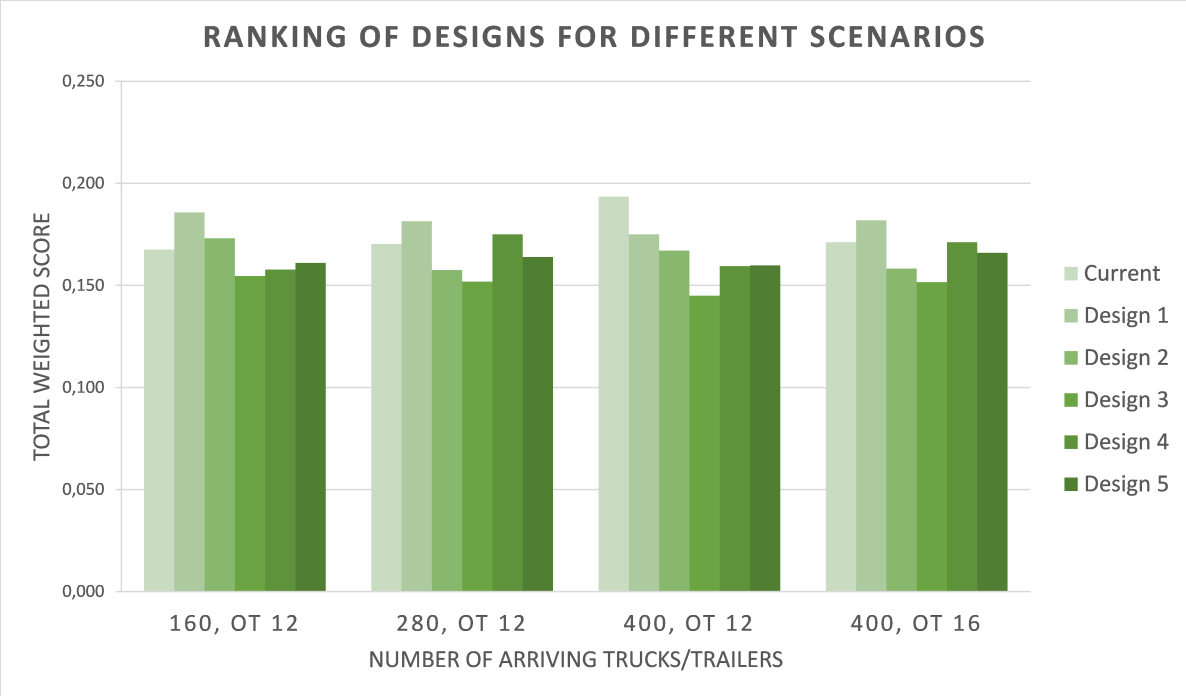


Figure 6.1: Ranking of designs per scenario

6.4 Conclusion

To answer the sub-question *"Which factors are decisive for the optimal logistics system of a convention center?"* an analytical hierarchy process was performed and interviews were carried out. In the AHP eight criteria were introduced and a pairwise comparison was made between these criteria by employees of the RAI. These employees are a traffic manager, a manager of the traffic department and the interim manager. The outcomes showed that these persons had different opinions on which criteria are most important. From these opinions a combined pairwise comparison matrix was made. This matrix showed that the overall opinion is that the criterion space is the most important followed by nuisance and flexibility. The criteria which are considered least important are delivery time, unloading time and costs.

After assigning the weight to the criteria, the data obtained from the simulation runs was normalised. For the criteria costs and flexibility a different approach was used since it was hard to express these criteria in numerical values. For both criteria a pairwise comparison is executed to determine the normalised score. With the use of these normalised data a ranking of the designs can be made. This is done by multiplying the normalised data with the criteria weights.

Overall, design 1 and the current design had high rankings in all scenarios and design 3 ranked lowest in all scenarios. The differences between the design scores are small. Therefore, it is hard to say that one of the designs stands outs as the best choice for the RAI. The scores of the criterion space are almost similar for the five designs. The space consists of the sum of the space needed for unloading spots and the space needed for the buffer space. Design 1 and 3 need much more buffer space than the other designs; however, only a small difference is shown in the score on space. The required buffer space is small compared to the space needed for the amount of unloading spots. This could mean that there is an underestimation of the buffer space. The buffer space is the most important criterion. Therefore, the buffer space could be of more importance than the outcomes show.

7 | Conclusions & Recommendations

In this chapter the sub-questions will be answered, followed by the answer on the main research question. These answers are based on the case-study, literature study and the simulation outcomes. After the conclusions a discussion of this research will follow and, finally, recommendations for the RAI and future research are given.

7.1 Conclusions

The first sub-question within this research focused on understanding the problems that convention centers are facing regarding logistics.

1. Which logistic problems are convention centers facing?

Most convention centers are located near or within cities since a good connection to transportation and tourist attractions increases the competitiveness of the convention center. However, a location within cities also leads to several challenges. These challenges are a lack of space, environmental issues and nuisance. Space within cities is limited and therefore expansion of convention centers is almost impossible. Within cities stricter rules and regulations are implemented to reduce negative side effects such as noise and emissions from transportation. This means that convention centers have to conform to these rules and regulations as well.

Besides problems regarding the location of convention centers, there are other challenges. These challenges are time-critical logistics, communication and flexibility. The build-up and break-down of a convention happens within a few days. Making the deadlines is of great importance and logistics should be able to make this happen. A disruption within the logistic process could lead to a delay. To be able to make these deadlines, the logistics should be flexible and ensure good communication between involved parties. Flexibility means that all types of goods can be handled and that in case of a disruption logistics can still continue. Good communication can ensure a smooth build-up. If all involved parties are well informed and all information is known before hand logistics could operate more efficient. However, it is often the case that details about logistics are unclear, which results in a chaotic situation.

Since literature on how convention centers can improve their logistic performance is lacking it is unclear how they should go about this. This research focuses on filling this research gap. To see which technologies and strategies could be adapted to improve logistic performance and overcome the problems mentioned literature and interviews were used to answer the second sub-question:

2. Which technologies and strategies can be used to improve logistic performance at convention centers or similar industries?

Within the literature on convention centers possible solutions are mentioned to improve logistics. These solutions are the implementation of IT systems such as RFID and outsourcing of logistic processes. The amount of literature on convention center logistics is limited; therefore, other industries such as ports, warehouses and city logistics were researched. These industries make use of several technologies, which can also be applied to improve convention center logistics. These technologies are: truck appointment systems, automated guided vehicles, conveyors, cross-docking, underground logistics and IT systems. The use of a truck appointment system can reduce congestion and waiting times since it controls the arrival process of trucks and trailers. The use AGVs, RGVs and conveyors automate the transportation of goods. This can reduce labour costs and human errors and improve productivity and consistency. Implementation is challenging since it requires infrastructure adjustments. Cross-docking is a strategy which reduces storage space and costs. Underground logistics decreases the nuisance of logistics to the neighbourhood. Underground transportation is also faster since there are no disturbances. However, construction of underground transportation is complex and has high costs. IT systems are needed to support technologies and strategies. Most of the technologies mentioned require IT systems to operate them, such as RFID. RFID can be used to identify pallets and vehicles. With the help of IT systems the sharing of information becomes easier, which can lead to more efficient logistics.

The third sub-question focused on how the current logistics system works:

3. How is freight currently transported to, from and within the RAI and why is it not optimal?

The current transportation to from and within the RAI is not optimal due to several reasons. The main reasons are a lack of communication with involved parties, unloading times often exceed the maximum time limit and considerable nuisance to the neighbourhood. The lack of communication with involved parties causes extensive waiting times and peak-behaviour. The RAI improved their communication to transporters by implementing online traffic regulations. However, information from transporters and the logistic partner to the RAI is still lacking: it is unclear how many trucks or trailers arrive at a certain date and time, how much load they carry and which destination they have. In the current situation trucks and trailers can arrive whenever they want. The unloading process of trucks and trailers is time consuming in the current situation. Trucks and trailers are unloaded one pallet at a the time, either by hand or with a forklift. Delivering a pallet can take several minutes and therefore maximum unloading times are often exceeded. There is little enforcement against truck or trailers exceeding the maximum times. This results in trucks or trailers occupying unloading spots for hours. This decreases the capacity of the RAI and can lead to higher waiting times. In the current situation the unloading spots for the north side are located near residential areas, which causes nuisance to the residents.

Data of the current system was obtained and analysed to determine its performance and answer sub-question 4:

4. How does the current logistics system affect performance, nuisance and space?

To determine the performance of the current system data was analysed. The data set used is an empirical data set obtained during a big convention held at the RAI. This data set contained arrival dates, arrival times and destinations of trucks and trailers. An experiment was carried out to obtain more data such as: actual unloading time, time to unload a pallet, speed of forklifts, EPTs and pallet jacks. The performance is expressed in unloading time, delivery time, waiting time and the number of forklifts/EPTs used. The data showed that the arrival of trucks and trailers has a high peak in the morning between 7 a.m. and 10 a.m., within this block 62% of the vehicles arrive. From all trucks and trailers arriving at the RAI, 60% has a destination on the north side. This means that if 280 trucks and trailers arrive at the RAI 168 trucks and trailers cause nuisance to the neighbourhood. The average unloading times for trailers are 95 minutes and for trucks 60 minutes, which is above the maximum limit. The capacity and the occupied logistic space on the work sites during a full complex event is 46 trailers and 58 trucks. In the current logistics system buffer spaces are not needed since pallets are directly delivered to the stand.

A DES simulation model was made of the current situation. The model is verified and validated with multiple tests. The model can be used to gather information about the outcomes of different logistic designs. The outputs of the simulation model showed a maximum waiting time of 115 minutes and an average delivery time of 52 minutes per pallet.

The DES model is adjusted to see the effect of different logistics system designs, which answers sub-question 5:

5. Which logistics system designs can be implemented and how do they affect the performance, nuisance and space?

Five different designs were introduced based on ideas from the RAI, on the requirement analysis and literature. All designs include the following strategies: a truck appointment system, extended operational times and cross-docking. This decision was made since a truck appointment system and extending operational times have a positive effect on unloading and waiting times. Cross-docking can reduce the unloading times with almost 50%. A combination of these three strategies showed positive effects on the performance and was therefore included in all designs. All designs use a tunnel from the south side to the north side to transport goods. Design 1 uses EPTs driven by humans to deliver the goods from south to north. In design 2 trucks and trailers drive through the tunnel and unload in a logistic center underneath hall 7. From here goods are transported to the final location with EPTs. Design 3 uses two conveyors to transport goods to the other side. At the north side EPTs are used to transport the goods to the stands. In design 4 RGVs are used to transport goods to the north side, and from here EPTs are used for the final transportation to the stand. Design 5 is similar to 4; however, instead of using RGVs, AGVs are used.

All designs show the same unloading times since they use the same unloading process. The unloading times are around 50 minutes for a trailer and 40 minutes for a truck. Design 2 has the longest waiting times since the trucks and trailers have to wait at the south side until an unloading spot becomes available. Waiting times occur mostly during busier days. By increasing operational time the waiting times can be reduced for all designs. Design 2 has the shortest delivery times, followed by designs 4 and 5. Design 1 and 3 show long delivery times since pallets spend more time within the buffer. The buffers for design 2, 4 and 5 are small (around 50 pallets) compared to the buffers of design 1 (up to 876 pallets) and 3 (up to 1300 pallets). Design 3 uses the smallest amount of EPTs and design 1 the most. All designs lead to a zero percent usage of the north side, which means that there will be no nuisance to the neighbourhood.

To determine which factors are important to decide which design is optimal, the AHP method is used. This method gives an answer to sub-question 6 and the main research question:

6. Which factors are decisive for the optimal logistics system of a convention center?

With the AHP method weights are assigned to the factors/criteria that are of importance when deciding on a new design. In the AHP eight criteria were introduced, these are the KPIs: unloading time, waiting time, delivery time, space, number of forklifts/EPTs, nuisance and costs. The criterion flexibility is added since this is also an important aspect of the logistics system at the RAI. Costs and flexibility are not expressed in a numerical value. However, the AHP method is able to include these kind of criteria as well. To determine the weights several employees of the RAI were asked to perform a pairwise comparison of the criteria. These persons are a traffic manager, a manager of the traffic department and the interim manager. The outcomes of the AHP showed that the overall opinion is that the criterion space is the most important, followed by nuisance and flexibility. The criteria which are considered to be least important are delivery time, unloading time and costs.

After answering these sub-questions the main research question can be answered:

How can the RAI redesign the freight logistics system to reduce negative external effects, improve logistic performance and maintain commercial space?

Redesigning the logistics system at the RAI would require severe changes. In order to be able to shift the logistic from the north side, to the south side several changes have to be made. In the current situation the capacity of unloading spots on the north side is much larger than the capacity created at the NLN, in fact the capacity will decrease with 70%. In order to still be able to handle the same amount of incoming trucks and trailers the logistic process has to be more structured. Several strategies were introduced to improve performance, reduce nuisance and maintain commercial space.

A strategy to gain more control over the arrival process is the implementation of a truck appointment system. This system reduces peak-behaviour and spreads the arrivals evenly over the day. Depending on the amount of arriving trucks and trailers, the operational time should be adjusted. During busy days the operational times should be extended to spread out trucks and trailers over the day. However, increasing operational times can lead to complaints from stakeholders such as deliverers and traffic employees. The view of these stakeholders should be known to see if extending operational times is a possibility.

The current unloading process is time-consuming, which leads to trucks and trailers spending too much time at unloading spots. In order to decrease unloading times, cross-docking can be implemented. Cross-docking can decrease unloading times with 50%. However, a buffer space is needed to store goods. The positive effect of cross-docking is only applicable to trucks and trailers that unload with the logistic partner. Self-unloading is not affected by this. Therefore, the decision can be made to no longer allow self-loading. A downside of cross-docking are the higher costs. The costs are expected to be higher than self-unloading. To make use of the services of the logistic partner, transporters have to pay the logistic partner and this could lead to dissatisfied customers since the costs will be higher.

A faster unloading process is desirable since it increases the capacity and reduces the waiting times. If trucks and trailers occupy an unloading spot for a shorter time, the unloading spot can handle more trucks and trailers per hour. This reduces the risk of trucks and trailers waiting and queuing for an available unloading spot. However, simulation outputs showed that waiting times can still occur even when strategies and new infrastructural designs are implemented. Therefore, an area should be constructed where a few trucks or trailers can wait in case this happens.

Delivery times are influenced by the design and by the speed within the halls. The data showed that the speed with which forklifts and EPTs are driven within the halls is lower than expected. The reason for this is that paths are blocked by obstacles and by other forklifts and EPTs. A better cooperation between traffic management and event management should be established to determine who is responsible for the objects on the paths and to determine how they should reduce these obstructions. A reduction of obstacles can lead to a higher speed and faster deliveries. If deliveries are made delivery times will decrease and less forklifts and EPTs are required.

In all designs the number of required forklifts and EPTs increased compared to the current situation. More forklifts are needed since in the designs self-loaders are no longer allowed. This means that all incoming trucks and trailers have to be unloaded by forklifts. Also, in most designs a larger distance has to be covered by the EPTs to deliver the goods to the stand within the hall.

The required space is influenced by the number of unloading spots and the required buffer space. In all designs the space required for unloading spots decreased. This is the case since the north side will be closed off. Only 30% of the current capacity of the north side will be relocated, which reduces the space required for unloading spots. The buffer space that is required differs for every design. Within the AHP the total space consists of the space required for the unloading spots and the required buffer space. Compared to the space required for unloading spots, the buffer space constitutes only a small percentage of the total space. The outcomes are based on the total space and therefore the differences in buffer space are not clearly visible for the designs.

All designs reduce the nuisance to the neighbourhood since trucks and trailers will no longer use the north side for unloading. Trucks and trailers will only use the south side of the RAI. Implementing one of the proposed designs will be costly since a tunnel or several tunnels need to be constructed. Therefore, all designs will have high investment costs.

Overall, design 1 scored best and seems the most promising. It offers high flexibility, performs well and has low costs. When many trucks and trailers have to be handled within limited operational time, the current design scores best. The current design has more capacity compared to the other designs. Therefore, all designs require more control of the arrival process of trucks and trailers and extended operational times. A disadvantage of design 1 is that it needs more buffer space compared to designs 2, 4 and 5. As mentioned before, the required buffer space is small compared to the total space. However, the required buffer space should be included when deciding on a design.

Designs that reduce buffer space and reduce the number of manually driven EPTs are design 4 and 5. They score lower on flexibility since it would be harder to handle goods that do not arrive on pallets. With these designs higher investment scores are expected since these systems require many infrastructural adjustments and technologies. An interesting option is combining design 1 with design 4 or 5. In this case odd-sized goods can be transported with EPTs or forklifts and goods on pallets with automated vehicles. By doing this the buffer sizes can be kept low and the amount of manual EPTs can still decrease. Within this research the automated vehicles are only implemented within the tunnel since the chaotic situations within the halls would be too challenging for this type of vehicle. However, if the RAI is able to structure and control the situation within the halls it could be possible to extend the use of automated vehicles in the future.

Design 2 and 3 are the least desirable options. Design 2 performs unstably. It suffers from high waiting times compared to the other designs and is the most expensive option. Design 3 needs a large amount of buffer space and is the least flexible. The current design suffers from long waiting times, unloading times and causes considerable nuisance. However, it is ranked high since it has low investment costs, uses a small amount of EPTs and forklifts and is highly flexible.

Implementing a truck appointment system, cross-docking and extending operational times will increase the performance of all designs and even the performance of the current situation. With the implementation of one of the five proposed designs the logistic space at the north side is no longer needed, which reduces the nuisance. The amount of logistic space needed within the designs is smaller than in the current situation. The proposed designs showed that with the implementation of the three strategies mentioned above they are able to handle up to 400 trucks and trailers without exceeding unloading time limits and without extensive waiting times.

7.2 Discussion

This research focused on convention center logistics and how they can improve their performance. Limited research has been done so far. However, logistics are highly important for conventions. In literature on logistics of other industries several strategies were found to improve logistics of convention centers. The conducted research analysed how convention center logistics works and which strategies would be suitable to implement. Besides finding suitable strategies, the effect of them on convention center logistics has been studied as well. The outcomes of this research offer general indications on how convention centers can improve their logistics, and more detailed indications on how the RAI Amsterdam can improve their logistics.

The conducted research also has its limitations. First, certain assumptions are included within the simulation model since data on these aspects was missing. For example, data was missing on truck and trailer loads. The loads of trucks and trailers are based on assumptions made by experts at the RAI. If these assumptions differ considerably from the actual data this can lead to deviating outputs and wrong conclusions. However, all the outputs of the model were discussed with traffic managers to check whether these outputs seemed legit.

Second, the simulation model is missing a lot of details, which would be important in a real world situation. For example disruptions, the situation within the halls, usage of the buffer area in Westpoort, including the packaging of delivered goods and the situation on egress and access roads are not included. Expanding the model with these kind of details would give a more extensive overview on how the designs would work. However, the scope of this project was to find out which strategies and designs would be promising (based on the situation on the RAI site) for further investigation and this has been accomplished.

Third, a convention consists of two main phases: the build-up and the breakdown phase. Within this research only the build-up is included. This decision was made since it has higher arrival peaks and the breakdown is more complex compared to the build-up. Creating a simulation model from the breakdown would have taken much more time and would have required even more assumptions. Since a simulation model for the build-up has already been made, it would be easier to adjust this model in the future to a break-down simulation.

Fourth, there is a potential underestimation of buffer space in the outcomes. The space is included as the space needed for unloading spots and the buffer space. The space required for unloading spots is large compared to the required buffer space. A design which uses double the amount of buffer space is not scoring that much worse within the AHP. Since space is an important factor for convention centers this underestimation of buffer space should be taken into account when deciding on a design.

Finally, the conducted research was performed for the logistics of the RAI. The simulation model is based on the infrastructure and the data obtained from the RAI. This means that outcomes and conclusions are specific for the logistics of the RAI and the optimal design for the RAI cannot be directly applied to other convention centers, since their situations could be different. However, the research showed strategies such as a truck appointment system and cross-docking which could work for other convention centers in general.

7.3 Recommendations

Based on this research recommendations can be given to the RAI. Implementing one of the designs is not possible within a short period of time. Construction of large infrastructure projects take years. However, the RAI can already start improving their logistics system. They should start with the implementation of a truck appointment system. The implementation of such a system could already reduce peak-behaviour and it gives the RAI and deliverers the time to get used to this system. Also, the possibility of extending operational times during busy days should be taken into account. As mentioned before, the possible negative effects of extending operational time should be researched. The opinion of the employees, the logistic partner and the convention organisers should be known and taken into account. If they are against the idea of extending operational times this could lead to complaints or even the loss of certain conventions. Furthermore, the costs of extending the operational time should be known. More employees are needed to cover the time and this increases costs.

The RAI should also start a cross-docking trial and see how this actually influences unloading times of trucks and trailers. Small buffer areas should be established on the work sites. Good communication with the logistic partner is of importance to successfully implement this trial. Based on the outcomes of this trial further decisions can be made on whether to allow self-loading or not in the future. It is recommended that the RAI investigates how customers would react to the fact that they are no longer allowed to self-load. Using only the services of the logistic partner for unloading increases the costs. The RAI should look into ways to cover these costs.

Based on the outcomes of this research a design with the new logistic center on the south side seems preferable. Design 1 scored best within the AHP; however, it requires much buffer space. The RAI should investigate if there is enough space for the required buffer space. If this is the case the design could be implemented. Design 1 can be improved with the implementation of automated vehicles, this reduces the required buffer space. The RAI would be a pioneer since they would be the first convention center to incorporate these kind of vehicles within their logistics. Implementation of automated vehicles requires investment costs; however, they can reduce labour costs in the future. The first step is to incorporate these vehicles within a stably-controlled environment which is the tunnel. If the automated vehicles work as expected the RAI can think about options to extend the transport with automated vehicles to the halls. This would especially be the case with autonomous vehicles, since they do not require special infrastructure. More research should be done as to which type of automated vehicles is suitable and is preferred by the RAI. If the RAI decides to automate transportation to the halls as well research should be done on how the situations within halls can be structured to allow automated vehicles to operate there. Another important aspect when automating logistics systems is the implementation of RFID. With the use of RFID all goods are labelled with a tag. This tag can be scanned by staff or automated vehicles and it is immediately clear where goods should go.

Finally, the RAI should try to find out if closing off the north side entirely is feasible. In the future the RAI wants to transform the north side into a park without any space for logistics. This means that all goods will have to be transported from the south side via the tunnel. However, a tunnel has height and width restrictions. This could mean that large objects cannot pass through this tunnel. Since the RAI hosts conventions such as the HISWA where entire boats are placed within halls, there should always be an option to deliver these objects. Closing off the north side entirely would make the delivery of these objects almost impossible. Another aspect why closing off the north side entirely is problematic, are the really busy days that occur a few times a year. Since capacity on the newly constructed logistic space is limited, it will be difficult to handle all traffic on the most busy days. Keeping space available on the north side provides more capacity and it can be used as an emergency option for those days. It can also serve as a plan B when there are defects within the tunnel. Therefore, it is recommended to keep space available at the north side for logistics and slowly decrease the capacity on the north side based on how the design is functioning. Keeping the north side partly open still causes nuisance to the neighbourhood. However, really busy days only occur a few times a year.

7.4 Future research

During this research several subjects for further research emerged. One of these subjects is the influence of the strategies and designs on the surroundings of the convention center. The scope of this research is only focused on the RAI site and not on its surroundings. However, the strategies and proposed designs could influence these surroundings. For example the traffic situation on access and egress roads can be influenced by these changes. It is important to research how these strategies and designs would influence the surroundings before implementing them. Therefore, it is recommended to research this in the future.

The simulation model could be improved with more accurate data. Every convention is different and has its own characteristics. The current simulation model is based on a data set from one convention. With the collection of data during other conventions the simulation model could be adjusted for these particular conventions. Within the current simulation model several assumptions are used such as: load of vehicles, share of self-loaders. If data could be collected on these aspects assumptions would no longer be necessary and this would improve the simulation model. Therefore, more detailed data should be collected in the future.

It is also important to research the break-down process of a convention. The break-down is more complex since goods first have to be collected before they can be loaded onto the truck or trailer. Investigating how these processes could be redesigned in combination with the optimal design for the build-up is important. If the design is only able to handle build-up and not the break-down the design should not be implemented.

Finally the influence of the situation within halls on the speed of forklifts and EPTs should be researched. This is outside the scope of this research but could have considerable influence on delivery times and the required number of forklifts and EPTs. This research showed that the speeds within halls are low and by adjusting the paths and regulations within halls the speed could be increased. With this increase delivery times will decrease and it might be the case that fewer EPTs will be needed.

References

Abar, S., Theodoropoulos, G. K., Lemarinier, P., & O'Hare, G. M. (2017). Agent based modelling and simulation tools: A review of the state-of-art software. *Computer Science Review*, *24*, 13–33. doi: 10.1016/j.cosrev.2017.03.001

Afweging opties logistiek rai terrein. (23-01-2020). Amsterdam.

Amsterdam, G. (15-10-2019). *Organisatie.* Retrieved 26-11-2019, from `https://www.amsterdam.nl/bestuur-organisatie/organisatie/`

Arends, G., & de Boer, E. (2001). Tunnelling of infrastructure: from non-considered to ill considered — lessons from the netherlands. *Tunnelling and Underground Space Technology*, *16*(3), 225–234. doi: 10.1016/S0886-7798(01)00043-8

Ashrafian, A., Pettersen, O.-G., Kuntze, K. N., Franke, J., Alfnes, E., Henriksen, K. F., & Spone, J. (2019). Full-scale discrete event simulation of an automated modular conveyor system for warehouse logistics. In F. Ameri, K. E. Stecke, G. von Cieminski, & D. Kiritsis (Eds.), *Advances in production management systems. towards smart production management* (Vol. 567, pp. 35–42). [S.l.]: SPRINGER NATURE. doi: 10.1007/978-3-030-29996-5{\textunderscore}4

Barriball, K. L., & While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of advanced nursing*, *19*(2), 328–335. doi: 10.1111/j.1365-2648.1994.tb01088.x

Binnenlands Bestuur. (2019). *Amsterdam weert all diesel-en benzineauto's per 2030.* Retrieved 18-12-2019, from `https://www.binnenlandsbestuur.nl/`

Buck Consultants. (2019). *Analyse nieuwe logistieke systeem rai amsterdam.* Nijmegen.

Caballini, C., Mar-Ortiz, J., Gracia, M. D., & Sacone, S. (2018). Optimal truck scheduling in a container terminal by using a truck appointment system. In *2018 21st international conference on intelligent transportation systems (itsc)* (pp. 2525–2530). IEEE. doi: 10.1109/ITSC.2018.8569623

Caro, J. J., & Möller, J. (2016). Advantages and disadvantages of discrete-event simulation for health economic analyses. *Expert review of pharmacoeconomics & outcomes research*, *16*(3), 327–329. doi: 10.1586/14737167.2016.1165608

Chen, G., Govindan, K., & Yang, Z. (2013). Managing truck arrivals with time windows to alleviate gate congestion at container terminals. *International Journal of Production Economics*, *141*(1), 179–188. Retrieved from `http://www.sciencedirect.com/science/article/pii/S0925527312001417` doi: 10.1016/j.ijpe.2012.03.033

Chen, J. C., Cheng, C. H., Wang, K. J., Huang, P. T. B., Chang, C. C., Huang, C. J., & Ting, T. C. (2011). Application of rfid to warehouse management. *Key Engineering Materials*, *486*, 297–300. doi: 10.4028/www.scientific.net/KEM.486.297

Clausen, U., de Bock, J., & Lu, M. (2016). Logistics trends, challenges, and needs for further research and innovation. In M. Lu & J. de Bock (Eds.), *Sustainable logistics and supply chains* (pp. 1–13). Cham: Springer. doi: 10.1007/978-3-319-17419-8{\textunderscore}1

Communities and local governments. (2009). *Multi-criteria analysis: A manual.* Wetherby: Communities and Local Government.

Creazza, A., Colicchia, C., & Dallari, F. (2015). Designing the venue logistics management operations for a world exposition. *Production Planning & Control*, *26*(7), 543–563. doi: 10.1080/09537287.2014.929190

Dablanc, L. (2007). Goods transport in large european cities: Difficult to organize, difficult to modernize. *Transportation Research Part A: Policy and Practice*, *41*(3), 280–285. Retrieved from `http://www.sciencedirect.com/science/article/pii/S0965856406000590` doi: 10.1016/j.tra.2006.05.005

Defense Acquisition University. (2001). *Systems engineering fundamentals.* Virginia.

Dubiel, B., & Tsimhoni, O. (2005). Integrating agent based modeling into a discrete event simulation'. In *Proceedings of the 37th conference on winter simulation* (pp. 1029–1037). [Place of publication not identified]: Winter Simulation Conference. doi: 10.1109/WSC.2005.1574355

Dziadkiewicz, M., Kadlubek, M., Legowik-swiacik, S., & Baskiewicz, N. (2016). The importance of logistics infrastructure in mass event management. *Valahian Journal of Economic Studies*, *7*(4), 37–44.

ExhibitCity. (2014). *Convention centers face fierce competition | exhibit city news.* Retrieved 14-5-2020, from https://exhibitcitynews.com/convention-centers-face-fierce-competition/

Felício, J. A., Caldeirinha, V., & Dionísio, A. (2015). The effect of port and container terminal characteristics on terminal performance. *Maritime Economics & Logistics*, *17*(4), 493–514. doi: 10.1057/mel.2014.33

Ferrara, A., Gebennini, E., & Grassi, A. (2014). Fleet sizing of laser guided vehicles and pallet shuttles in automated warehouses. *International Journal of Production Economics*, *157*, 7–14. Retrieved from http://www.sciencedirect.com/science/article/pii/S0925527314001911 doi: 10.1016/j.ijpe.2014.06.008

Fetch Robotics. (2018). *Amrs vs. agvs: What's the difference?* Retrieved 28-5-2020, from https://fetchrobotics.com/fetch-robotics-blog/amrs-vs-agvs-whats-the-difference/

Friswell, R., & Williamson, A. (2019). Management of heavy truck driver queuing and waiting for loading and unloading at road transport customers' depots. *Safety Science*, *120*, 194–205. Retrieved from http://www.sciencedirect.com/science/article/pii/S0925753518320708 doi: 10.1016/j.ssci.2019.06.039

Gemeente Amsterdam. (n.d.). *Amsterdam lanceert plan voor schonere lucht.* Retrieved 02-08-2019, from www.amsterdam.nl

Gemeente Amsterdam. (2018). *Motie van de leden n.t. bakker, kat, bloemberg-issa, ceder en van soest inzake de uitbreidingsplannen van rai amsterdam met betrekking tot half vijf van het rai-complex* (No. 942). Retrieved from www.amsterdam.raadsinformatie.nl

Goepel, K. D. (2018). Implementation of an online software tool for the analytic hierarchy process (ahp-os). *International Journal of the Analytic Hierarchy Process*, *10*(3). doi: 10.13033/ijahp.v10i3.590

Gokhale, S. S., & Trivedi, K. S. (1998). Analytical modeling. *Encyclopedia of Distributed Systems.* Retrieved 15-11-2019, from https://pdfs.semanticscholar.org/1aba/fda26fcf84d5662d5d2d35702f36f114c3c2.pdf

Graves, A. (n.d.). *What is dmadv?* Retrieved 21-8-2019, from https://www.sixsigmadaily.com/what-is-dmadv/

Haixia, G. (2010). Analysis on the outsourcing of chinese exhibition logistics. In *International conference on logistics systems and intelligent management, 2010* (pp. 1119–1122). Piscataway, NJ: IEEE. doi: 10.1109/ICLSIM.2010.5461132

Handfield, R. (2013). *Embracing global logistics complexity to drive market advantage.* Hamburg: DVV Media Group.

Hassan, M., Ali, M., & Aktas, M. (Eds.). (2011). *International conference on business management and electronic information (bmei), 2011: 13-15 may 2011, guangzhou, china ; proceedings ; [including] 2011 international conference on supernetworks and system management (icssm 2011), may 29 to 30, 2011, shanghai, china.* Piscataway, NJ: IEEE.

Hoad, K., Robinson, S., & Davies, R. (2007). Automating des output analysis: How many replications to run. In *Proceedings of the 2007 winter simulation conference* (pp. 505–512). Piscataway, NJ: IEEE. doi: 10.1109/WSC.2007.4419641

Hoogland, T. (n.d.). *Onderzoek optimaliseren logistiek.*

Hu, W., Dong, J., Hwang, B.-g., Ren, R., & Chen, Z. (2019). A scientometrics review on city logistics literature: Research trends, advanced theory and practice. *Sustainability*, *11*(10), 2724. doi: 10.3390/su11102724

Huynh, N., Smith, D., & Harder, F. (2016). Truck appointment systems. *Transportation Research Record: Journal of the Transportation Research Board*, *2548*(1), 1–9. doi: 10.3141/2548-01

Jacob, M. (2013). Discrete event simulation. *Resonance*, *18*(1), 78–86. doi: 10.1007/s12045-013-0010-x

Jenab, K., Wu, C., & Moslehpour, S. (2018). Design for six sigma: A review. *Management Science Letters*, 1–18. doi: 10.5267/j.msl.2017.11.001

Ju, H. (2011). Modes construction and innovation of supply chain about convention and exhibition economy in china. In M. Hassan, M. Ali, & M. Aktas (Eds.), *International conference on business management and electronic information (bmei), 2011* (pp. 524–528). Piscataway, NJ: IEEE. doi: 10.1109/ICBMEI.2011.5920509

Jungheinrich. (2019). *Producten.* Retrieved 13-11-2019, from jungheinrich.nl

Kelton, W. D., Smith, J., & Sturrock, D. T. (2014). *Simio and simulation: Modeling, analysis, applications* (3. ed., rev ed.). Sewickley, Pa.: Simio.

Krauth, E., Moonen, H., Popova, V., & Schut, M. (2005, 01). Performance measurement and control in logistics service providing. In (p. 239-247).

Kucukaltan, B., Irani, Z., & Aktas, E. (2016). A decision support model for identification and prioritization of key performance indicators in the logistics industry. *Computers in Human Behavior*, *65*, 346–358. Retrieved from http://www.sciencedirect.com/science/article/pii/S0747563216306100 doi: 10.1016/j.chb.2016.08.045

Ladier, A.-L., & Alpan, G. (2016). Cross-docking operations: Current research versus industry practice. *Omega*, *62*, 145–162. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305048315001991 doi: 10.1016/j.omega.2015.09.006

Law, A. M., & Kelton, W. D. (1991). *Simulation modeling and analysis* (2nd ed. ed.). New York and London: McGraw-Hill.

Li, Z., & Liu, H. (2018). Summary of research on distribution centers. In K. Li, W. Li, Z. Chen, & Y. Liu (Eds.), *Computational intelligence and intelligent systems. part ii* (Vol. 874, pp. 238–250). Singapore: Springer. doi: 10.1007/978-981-13-1651-7{\textunderscore}21

Macharis, C., & Bernardini, A. (2015). Reviewing the use of multi-criteria decision analysis for the evaluation of transport projects: Time for a multi-actor approach. *Transport Policy*, *37*, 177–186. Retrieved from http://www.sciencedirect.com/science/article/pii/S0967070X14002285 doi: 10.1016/j.tranpol.2014.11.002

Maka, A., Cupek, R., & Wierzchanowski, M. (2011). Agent-based modeling for warehouse logistics systems. In D. Al-Dabass (Ed.), *Uksim 13th international conference on computer modelling and simulation (uksim), 2011* (pp. 151–155). Piscataway, NJ: IEEE. doi: 10.1109/UKSIM.2011.37

Maknoon, M. Y., & Baptiste, P. (2009). Cross-docking: increasing platform efficiency by sequencing incoming and outgoing semi-trailers. *International Journal of Logistics Research and Applications*, *12*(4), 249–261. doi: 10.1080/13675560903076081

Martina, C., Alessandro, P., & Fabio, S. (2018). Modelling of rail guided vehicles serving an automated parts-to-picker system. *IFAC-PapersOnLine*, *51*(11), 1476–1481. doi: 10.1016/j.ifacol.2018.08.295

Messe Frankfurt. (n.d.). *Logistic services.* Retrieved 4-10-2019, from https://www.messefrankfurt.com/frankfurt/en/services/logistics-traffic.html

Messe Muenchen. (n.d.). *Fairlog—the new logistics control system.* Retrieved 4-10-2019, from https://messe-muenchen.de/en/locations/services/trade-fair-services/fairlog/

Minis, I., Paraschi, M., & Tzimourtas, A. (2006). The design of logistics operations for the olympic games. *International Journal of Physical Distribution & Logistics Management*, *36*(8), 621–642. doi: 10.1108/09600030610702899

Montevechi, J. A. B., da Silva Costa, R. F., Leal, F., de Pinho, A. F., Marins, F. A. S., Marins, F. F., & de Jesus, J. T. (2008). Combined use of modeling techniques for the development of the conceptual model in simulation projects. *2008 Winter Simulation Conference*, 987-995.

Network, A. (27-3-2020). *Types of automated guided vehicles – general overview.* Retrieved 27-3-2020, from https://www.agvnetwork.com/types-of-automated-guided-vehicles#agc

Nilsson, D. (2001). Discrete event simulation as a performance analysis tool in agricultural logistics systems. *IFAC Proceedings Volumes*, *34*(26), 19–24. Retrieved from http://www.sciencedirect.com/science/article/pii/S1474667017336261 doi: 10.1016/S1474-6670(17)33626-1

Nowicka-Skowron, M., Nowakowska-Grunt, J., & Brzozowska, A. (2018). A logistics system in management of flows in the area of agribusiness. *Acta logistica*, *5*(3), 87–92. doi: 10.22306/al.v5i3.100

Olympia London. (n.d.). *Olympia london — voyage control.* Retrieved 4-10-2019, from https://www.voyagecontrol.com/olympialondon

Özgün, O., & Barlas, Y. (Eds.). (2009). *Discrete vs. continuous simulation: When does it matter?*

Pawlewski, P. (2015). Des/abs approach to simulate warehouse operations. In J. Bajo Pérez (Ed.), *Highlights of practical applications of agents, multi-agent systems, and sustainability* (Vol. 524, pp. 115–125). Cham: Springer. doi: 10.1007/978-3-319-19033-4{\textunderscore}10

Quak, H., & Tavasszy, L. (2011). Customized solutions for sustainable city logistics: The viability of urban freight consolidation centres. In J. A. E. E. van Nunen, P. Huijbregts, & P. Rietveld (Eds.), *Transitions towards sustainable mobility* (Vol. 43, pp. 213–233). Berlin and New York: Springer. doi: 10.1007/978-3-642-21192-8{\textunderscore}12

Rabe, M., Klueter, A., & Wuttke, A. (Eds.). (2018). *Evaluating the consolidation of distribution flows using a discrete event supply chain simulation tool: Application to a case study in greece.* doi: 10.1109/WSC.2018.8632266

RAI Amsterdam. (n.d.-a). *Jaarverslag 2018.* Amsterdam. Retrieved 02-08-2019, from www.rai.nl

RAI Amsterdam. (n.d.-b). *Jaarverslag met duurzaamheidsverslag 2017.* Amsterdam. Retrieved 02-09-2019, from www.rai.nl

Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A review of last mile logistics innovations in an externalities cost reduction vision. *Sustainability*, *10*(3), 782. Retrieved from https://www.mdpi.com/2071-1050/10/3/782/pdf doi: 10.3390/su10030782

Ren, M., Fan, Z., Wu, J., Zhou, L., & Du, Z. (2019). Design and optimization of underground logistics transportation networks. *IEEE Access*, *7*, 83384–83395. doi: 10.1109/ACCESS.2019.2924438

Ribino, P., Cossentino, M., Lodato, C., & Lopes, S. (2018). Agent-based simulation study for improving logistic warehouse performance. *Journal of Simulation*, *12*(1), 23–41. doi: 10.1057/s41273-017-0055-z

Robinson, S. (2011). *Conceptual modeling for discrete-event simulation.* Boca Raton: CRC Press.

Roeder, T. (Ed.). (2016). *Simulating complex service systems: Wsc'16 - winter simulation conference : Crystal gateway marriott, arlington, va, december 11-14, 2016.* [Piscataway, NJ]: IEEE.

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. Retrieved from http://www.sciencedirect.com/science/article/pii/037722179090057I doi: 10.1016/0377-2217(90)90057-I

Sargent, R. G. (2010). Verification and validation of simulation models. In I. Staff (Ed.), *Proceedings of the 2010 winter simulation conference* (pp. 166–183). [Place of publication not identified]: I E E E. doi: 10.1109/WSC.2010.5679166

Savelsbergh, M., & van Woensel, T. (2016). 50th anniversary invited article—city logistics: Challenges and opportunities. *Transportation Science*, *50*(2), 579–590. doi: 10.1287/trsc.2016.0675

Shahpanah, A., Shariatmadari, S., Chegeni, A., Gholamkhasi, A., & Shahpanah, M. (2014). Improvement in queuing network model to reduce waiting time at berthing area of port container terminal via discrete event simulation. *Applied Mechanics and Materials*, *621*, 253–258. doi: 10.4028/www.scientific.net/AMM.621.253

Sharma, S., & Pandey, S. K. (2018). Revisiting requirement analysis techniques and challenges. In M. Pant, K. Ray, T. K. Sharma, S. Rawat, & A. Bandyopadhyay (Eds.), *Soft computing* (Vol. 584, pp. 667–678). Singapore: Springer. doi: 10.1007/978-981-10-5699-4{\textunderscore}63

Swaak, P. (2018). *Logistiek masterplan 2018-2030.*

Sztrik, J. (2016). *Basis queueing theory: Foundations of system performance modeling.* GlobeEdit.

Tako, A. A., & Robinson, S. (2012). The application of discrete event simulation and system dynamics in the logistics and supply chain context. *Decision Support Systems*, *52*(4), 802–815. doi: 10.1016/j.dss.2011.11.015

Ullrich, G. (2015). Technological standards. In G. Ullrich & P. A. Kachur (Eds.), *Automated guided vehicle systems* (pp. 97–163). Berlin: Springer. Retrieved from https://doi.org/10.1007/978-3-662-44814-4_3 doi: 10.1007/978-3-662-44814-4{\textunderscore}3

Ultimation. (2019). *Conveyor types | different types of industrial conveyor systems.* Retrieved 27-3-2020, from https://www.ultimationinc.com/conveyor-technologies/conveyor-types/

User, S. (n.d.). *Types of automated guided vehicles – general overview.* Retrieved 2-10-2019, from http://www.agvnetwork.com/automated-guided-vehicles-technology/types-of-agv/types-of-automated-guided-vehicles-general-overview

van Berkel, A. (2020-02-29T13:28:27.000Z). *Parkeren algemeen: Bouwkundig detailleren - details bouwkunde.* Retrieved 13-5-2020, from https://berkela.home.xs4all.nl/cad%20vervoer/parkeren%20algemeen.html

Verbraeck, A. (2019). *Tb233a: Disrete modellen: College 2.1 - simulatie, conceptualisatie.*

Wan, L., Guan, Z., & Shao, X. (2011). Simulation based study on the layout of an enterprise distribution center. In *International conference on transportation, mechanical, and electrical engineering (tmee), 2011* (pp. 279–283). Piscataway, NJ: IEEE. doi: 10.1109/TMEE.2011.6199197

Wang, H. (2008). A review of six sigma approach: Methodology, implementation and future research. In *2008 international conference on wireless communications, networking and mobile computing* (pp. 1–4). Piscataway: Institute of Electrical and Electronics Engineers. doi: 10.1109/WiCom.2008.1887

Wang, L. Y., & Feng, Y. (2013). A study to setting function of queuing discipline in highway tollgate. *Advanced Materials Research*, *734-737*, 1594–1597. doi: 10.4028/www.scientific.net/AMR.734-737.1594

Yan, B., Chen, Y., & Meng, X. (2008-). Rfid technology applied in warehouse management system. In F. Yu, Y. Chen, & Q. Zhou (Eds.), *Cccm 2008* (pp. 363–367). Los Alamitos Calif.: IEEE Computer Society. doi: 10.1109/CCCM.2008.372

Yu, W., & Egbelu, P. J. (2008). Scheduling of inbound and outbound trucks in cross docking systems with temporary storage. *European Journal of Operational Research*, *184*(1), 377–396. doi: 10.1016/j.ejor.2006.10.047

Zhang, H., Zhang, Q., & Chen, W. (2019). Bi-level programming model of truck congestion pricing at container terminals. *Journal of Ambient Intelligence and Humanized Computing*, *10*(1), 385–394. doi: 10.1007/s12652-017-0641-y

Zhang, S. X. (2012a). Research on exhibition logistics information platform construction. *Applied Mechanics and Materials*, *241-244*, 3205–3208. doi: 10.4028/www.scientific.net/AMM.241-244.3205

Zhang, S. X. (2012b). Research on exhibition logistics information system designing. *Advanced Materials Research*, *605-607*, 479–482. doi: 10.4028/www.scientific.net/AMR.605-607.479

Zhu, X., & Yao, Q. (2011). Logistics system design for biomass-to-bioenergy industry with multiple types of feedstocks. *Bioresource Technology*, *102*(23), 10936–10945. Retrieved from `https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S0960852411012314/pdfft?md5=d6ba80466ddbd5e2c28eafa60aa55aec&pid=1-s2.0-S0960852411012314-main.pdf` doi: 10.1016/j.biortech.2011.08.121

Part VI

Appendix

A KPI relations

To get a better understanding of the relations between the KPIs and other factors a qualitative model is used (Figure A.1). In this model the expected relations between KPIs are visualised. The relationships between these factors are not quantified but based on general knowledge.

Within Figure A.1 the relationships between the KPIs and other factors are shown. Within the figure two sort of relationship are shown either a positive or a negative relationship. A positive relationship can be recognized by the green colour and the "+" symbol. A negative relationship by the red colour and the "-" symbol. A positive relationship means that if the factor increases the other factor increases as well. The negative relationship means that if the factor increases the other factor decreases.

For example if the unloading time of vehicles increases the spot occupation increases. If unloading takes more time the spot is occupied longer by that certain vehicle. And if the number of unloading spots increases the spots occupation reduces since vehicles are divided over more spots.

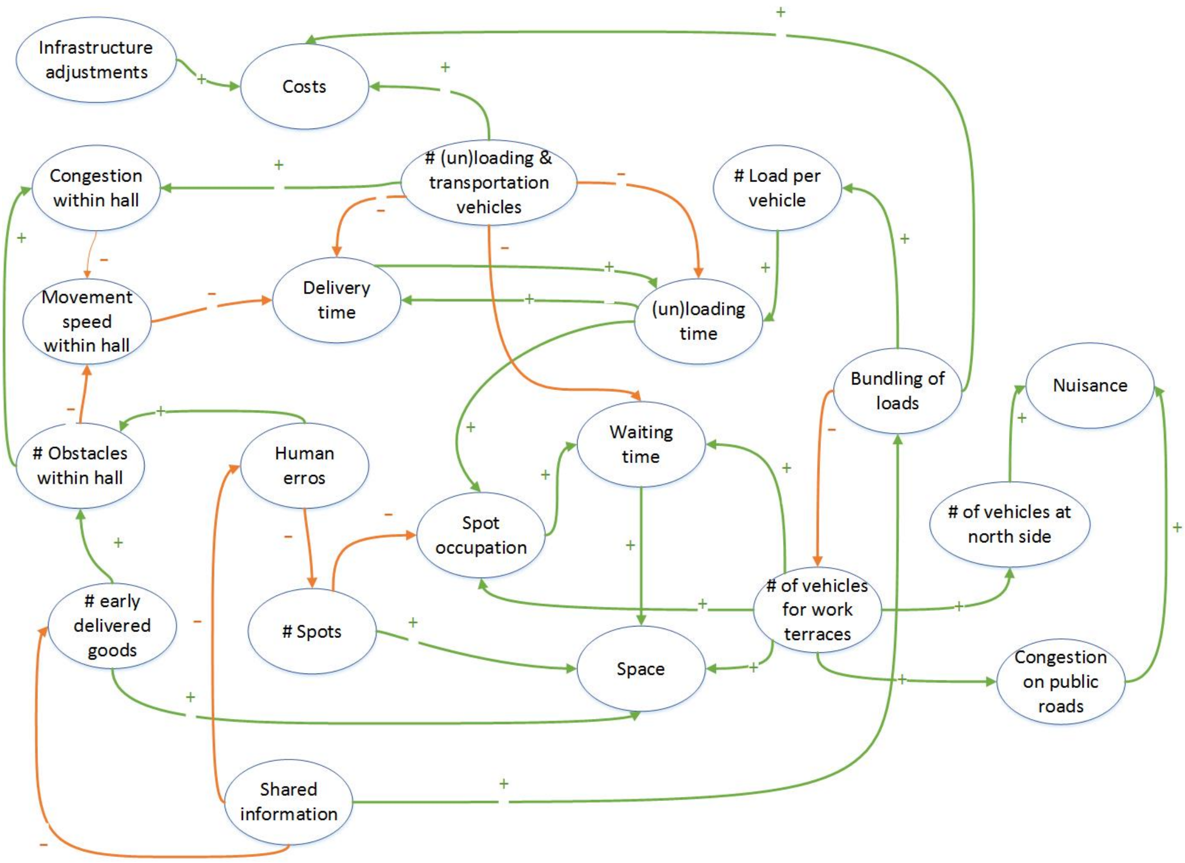


Figure A.1: Relationships KPIs

B | Data Gathering

To obtain needed data measurement at the RAI are performed. These measurements were performed to gain data that was still missing and is needed for the simulation model. The missing data are the times vehicles spend at the RAI working terraces and the moving speed of the goods from the truck to the final location. The measurements were performed during 4 days at the Aquatec. The Aquatec is a big convention that covers a part of the north side and the south side of the RAI. The processes for obtaining the trucks and trailers staying time and the movement speeds of goods will be described shortly.

B.1 Vehicle Time at RAI Working Terraces

Measurements were obtained on the P5A, P9 and P8. The following data was collected from the vehicles:

- Arrival time of the truck or trailer
- Start time unloading (the moment the trunk is opened)
- Finish time unloading (the moment when all goods are unloaded and the trunk is closed)
- Departure time of the truck or trailer
- Is the truck or trailer a self-loader or works it with the logistic partner
- License plate

The times were obtained with the help of a clock and the times are rounded on minutes. In total data from 52 trucks was collected. However, not all measurements are complete. For several vehicles the departure time is missing since they were still present on the working terrace while the measuring shift finished. These vehicles are still included in the data list since the other data that was collected is still of importance.

B.2 Movement Speed of Goods

The movement speed of goods are also measured during the 4 days. The measurements were obtained in hall 1. This is one of the largest halls of the RAI; therefore, many movements take place within this hall. In hall 1 a balcony is present, from this balcony there is a good overview of the hall and of the working terrace. Therefore it is possible to follow goods from the truck to the final location within the hall without disturbing the process. Within the halls a distinction is made between yellow paths and normal paths. Yellow paths have to be free from objects at all times whereas normal paths can be used as storage of objects as well. From the goods the following data is collected:

- Vehicle type used for movement (Forklift, EPT, pallet jack)
- Vehicle type used for unloading (Forklift, pallet jack)
- Stand number (final location or pick-up location of the goods)
- Entry or exit door (door where the goods leave the hall)

- Unload time (time to unload pallet or goods from the truck)
- Time to move goods from the truck to the entry of the hall
- Transportation time on yellow path
- Transportation time on normal path

The data is collected with a stopwatch and the times are rounded on seconds. For every part of the movement the time was noted. This means the time is started when the unloading starts and noted when the unloading has finished. Then the transportation time to the hall, the time spend on the yellow paths and the time spend on the normal paths is noted. With the knowledge of the entry/exit door and the stand number the distance can be determined with the floor plan. The distance covered and the time it took gives the average speed on the specific part of the transportation. These speeds can only be determined from the entrance/exit door to the stand since the distance outside the hall differs every time since there is no floor plan there. In total 35 measurements of the movement of goods were obtained.

C | Interviews

C.1 Traffic Manager

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: We zijn redelijk vrij om per evenement te besluiten wat het verkeersplan wordt. Dit verkeersplan bevat maatregelen en ideeën. Ook is er nu geen aanmeldt systeem waardoor daar ook geen back office voor nodig is.

Nadelen: Er is voor ogen wat er nodig zou moeten zijn voor een strakke logistiek. Evenementen moeten nu overtuigt worden om op die manier te gaan werken. Bij evenementen die meegaan in de nieuwe ideeën en maatregelen zien we dat de logistiek soepeler verloopt. De PMLA is hier een voorbeeld van daar mochten grote vrachtwagens alleen nog met de logistiek partner geladen en gelost worden. Bij het invoeren van een maatregel loopt het de eerste keer nooit optimaal maar de tweede keer gaat het al een stuk beter. Maar het overtuigen van deze evenementen om te veranderen is lastig. Mensen kunnen zich niet aanmelden er is geen inzage in wie er komen, wanneer ze komen en wat ze komen leveren, er is dus weinig coördinatie. Goederen worden soms te snel naar binnen gebracht terwijl deze eigenlijk nog niet nodig zijn hierdoor loop het in de hal vast en gaat laden en lossen nog minder snel. Met de huidige manier van communicatie wordt de standbouwer of de transporteur niet bereikt 10/20% is geïnformeerd de rest komt hier achter het verkeersplan, er zitten nu teveel schakels tussen. Het proces van het laden en lossen zelf gaat niet snel genoeg met name het moment van arriveren totdat er daadwerkelijk geladen en gelost wordt. Nadeel dat er per evenement verschil is in de hoofd logistieke partij en er ook nog veel externe partijen zijn waarmee samengewerkt moet worden.

Grootste reden waarom de logistiek op het moment aangepast moet worden?

Als we met de huidige logistiek ons werk goed doen kan het heel rustig en relaxed zijn zonder chaos. Het is op het moment niet heel slecht maar de druk vanuit de buurt en omwonenden beïnvloeden de situatie. Vroeger was er meer ruimte tegenwoordig zijn er veel meer huizen gebouwd rondom de RAI waardoor de beschikbare vierkante meters van de RAI afgenomen zijn. De RAI is steeds meer omringd door stedelijk gebied.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Het einddoel moet zijn dat er nooit meer verkeersstagnatie en drukte met vrachtwagens rondom de RAI is. De pieken moeten weggenomen worden zodat verkeer regelmatig over de dag aankomt in plaats van allemaal tegelijk. Vrachtwagens die bij de RAI aankomen moeten verwacht worden, er moet ruimte zijn en er moeten mensen klaar staan voor het laden en het lossen. Als de logistiek in de hallen meegenomen wordt moeten we ook weten wat er in een vrachtwagen zit en wanneer het naar binnen moet. Drukte op de werkterassen en hoeveelheid aan verscheidene voertuigen maakt de situatie onoverzichtelijk en soms onveilig, ook daarin zou er totale regie moeten zijn. Dit is op het moment lastig door de tijdsdruk.

Wat zou je zelf graag veranderd zien in de logistiek?

Wat ideaal zou zijn is als alles via een warehouse gaat. Alles wat bij de RAI komt wordt geregeld via het warehouse, alles via de logistiek partner, alles just-in-time, alleen gebruik van elektrische voertuigen en nooit meer files.

C.2 Traffic Employee

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: De buffer op de P20 wordt gebruikt voor registratie. Er is tussen de buffer en de RAI een goede samenwerking. Er is op de buffer genoeg ruimte en voertuigen komen op afroep naar de RAI. Beter om voertuigen te bufferen op de buffer dan dat ze rond de RAI staan te wachten. Logistieke partners werker vaak met slottijden voertuigen die de logistiek partner gebruiken worden aan de hand van die slottijden weggestuurd dit gaat ook steeds beter. De zelf lossers zijn het grootste probleem. Nadelen: Op de buffer komen ook veel voertuigen met kleine zendingen deze gaan nu allemaal los naar de RAI zou beter zijn om deze samen te voegen met behulp van een warehouse. De P9 wordt nog kleiner door de uitbreiding van hal 5 dus nog minder capaciteit voor voertuigen. Chauffeurs moeten soms even wachten voordat ze door mogen ene keer wordt er positief gereageerd andere keer negatief. Nadeel van de huidige buffer is dat deze bereikt wordt door drukke wegen en dat het een stuk rijden is al helemaal als er file staat. Als voertuigen gestuurd worden en aankomen op de RAI worden ze niet altijd meteen geholpen en staan ze te wachten tot de heftrucks beschikbaar zijn. Daardoor staan ze en op de buffer te wachten en op de RAI. Busjes moeten in principe via de garage lossen voor hallen 8 t/m 12 is dat fijn want dat is vlakbij. Maar voor hallen 1 t/m 7 moeten ze met karretjes de goederen verplaatsen dit is niet ideaal.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Half lege ladingen zouden samengevoegd moeten worden zodat er minder voertuigen naar de RAI komen. Implementeren van een warehouse is een oplossing maar hoe ga je dit communiceren naar alle partijen en zorgen dat dit goed gaat. Communicatie is moeilijk omdat chauffeurs de taal vaak niet spreken en vaak ook geen idee hebben voor welke stand ze komen leveren en welke hal. Op voorhand weten welke vrachtwagen komt voor welke hal en stand zou het een stuk makkelijker maken.

Wat zou je zelf graag veranderd zien in de logistiek?

Er is al veel verbeterd afgelopen jaren. Het vooraf aanmelden en met slottijden werken zou mooi zijn. Bloktijden voor de logistiek partner waarop zij alleen recht hebben zou misschien uitgebreid moeten worden. Nu is het meestal één dag maar door dit uit te breiden kan je mensen wat meer pushen om met de logistiek partner samen te werken.

C.3 Event Manager

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: Nauwelijks wachtrijen voor iemand op de bonnefooi naar de RAI komt. Strakke regie buiten, en een duidelijk logistiek planning. Deze planning is wel rigide dus moeilijk van af te wijken. De logistiek is veilig door gefaseerd opbouwen binnen. Eerst elektriciteit dan de vloer dan pas de stands en daarna de inrichting. In de hal is er verplichting voor gele paden die altijd vrij moeten zijn zodat de logistieke doorstroming mogelijk blijft. Hiervoor moet ook personeel ingezet worden. In het begin weinig respect voor gele paden maar dat wordt steeds meer.

Nadelen: Niet strak genoeg geregisseerd over het algemeen kan iedereen gewoon komen aanrijden. Hierdoor ontstaan veel piekmoment doordat alle bouwers rond het zelfde tijdstip willen starten. Spullen voor stands worden geleverd maar niet direct gebruikt hierdoor raken de paden verstopt en dit heeft invloed op het proces. Een nadeel is ook dat er soms een hele trailer komt voor één pallet.

Grootste reden waarom de logistiek op het moment aangepast moet worden?

De RAI ligt straks in een milieuzone en over 10 jaar mogen we hier niet meer komen met uitstoot gevende motoren. Maar ook de buurt heeft invloed maar de milieuzone lijkt mij een belangrijkere reden.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Op korte termijn is er minder ruimte dan voorheen om te lossen. Een oplossing hiervoor is gefaseerd bouwen en aanmelden op tijd-slots zodat de piek gereduceerd wordt. Op het moment mogen stand bouwers zelf bouwen wat ze willen een andere aanpak is uniforme standbouw. Hierbij zijn alle stands hetzelfde en het verschil in logistieke bewegingen is groot. Wij denken dat er meer voordelen zitten aan uniforme standbouw alleen de klanten moet je mee krijgen. Liever geen heftrucks meer in de hal maar EPTs. Met name tijdens inrichtingsdagen verbieden. De reden waarom ze nu wel toegelaten worden is omdat er grote tijdsdruk staat op opbouw en afbouw.

Wat zou je zelf graag veranderd zien in de logistiek?

Het idee met banden/tunnels onder de RAI door zou ik heel mooi vinden. Goederen komen via deze banden in het midden van de hal aan. Dit kost alleen gigantisch veel geld en is kostenverhogend voor je klanten. Ander interessant ontwerp is de spullen tot de deur brengen en vanaf daar met een robot naar de stand brengen.

C.4 Planning & Support

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: Het systeem is bekend, we doen het al een tijd en we weten wat we doen. Voor kleine evenementen werkt het prima. Wanneer het drukker wordt begint het wel lastiger te worden. Op de huidige manier kan je makkelijk bij elke hal komen en parkeren.

Nadelen: Overlast voor de buurt en we raken vol. Grote evenementen zijn lastig om te handelen waardoor we buiten het terrein moeten. Als planner moeten we de klant uitleggen waarom ze naar een extern terrein moeten, de klant moet dus mee veranderen. De ene klant doet dit makkelijker dan de ander.

Grootste reden waarom de logistiek op het moment aangepast moet worden?

De overlast die we veroorzaken voor de buurt en we worden uiteindelijk gedwongen door de gemeente met invoering van de milieuzone. Er is ook steeds minder plek voor logistiek door het uitbreiden van de hallen. Vroeger waren de bufferterreinen dichter bij de RAI nu steeds verder weg.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Het moet kunnen omgaan met verschillende evenementen en met voertuigen die spontaan aankomen. Logistiek binnen en buiten moeten meer op elkaar aangesloten worden. Een kosten component is ook belangrijk uiteindelijk moet iemand de rekening betalen. Het moet dus uiteindelijk kosten-efficiënt zijn.

Wat zou je zelf graag veranderd zien in de logistiek?

Ik geloof in de weg waar we nu inslaan. Van binnen wordt aangegeven dat er iets nodig is dat ligt al klaar op een extern terrein. Op afroep kunnen die goederen geleverd worden vanaf het externe terrein. Alles wordt geleverd aan de zuid kant en dan naar de hal getransporteerd.

C.5 Manager Traffic Department

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: Het werkt op dit moment. Elk evenement is op tijd opgebouwd en op tijd afgebouwd.

Nadelen: De mens inzet is nogal hoog. Te hoge impact op de buurt en de kans op voorbereiding van externe partijen is relatief laag. In totaal kan het beter door invoeren van maatregelen.

Grootste reden waarom de logistiek op het moment aangepast moet worden?

Logistiek heeft binnen de RAI bijna nooit aandacht gehad. De verandering komt daardoor niet snel van binnen uit en komt dus van buiten af. Dit is de buurt die steeds kritischer wordt. En alle steden worstelen met een prettig klimaat voor bewoners waardoor er kritischer gekeken wordt naar partijen die vervuilen.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Er moet veel meer regie komen dit kan afgedwongen worden door een extern warehouse. Hierdoor kunnen vrachtwagen bewegingen gereduceerd worden. De vrachtwagen bewegingen die gemaakt worden daar is ook regie over en je kan er voor zorgen dat deze zero-emissie gedaan worden. Communicatie moet beter. En het onzichtbare deel op de RAI dus dat de logistiek minder zichtbaar is voor de buurt en bezoekers. Ik zie de eisen ook in deze volgorde.

Wat zou je zelf graag veranderd zien in de logistiek?

Als alles kon zou ik een herontwerp doen van de RAI waar het complex opnieuw opgebouwd wordt van onder naar boven. Op de -1 alleen maar logistieke ruimte zodat het vanaf onderaf de hal in kan. Daarboven parkeergarages en commerciële ruimte.

C.6 Interim Manager

Wat zijn de voordelen en nadelen van hoe de logistiek op het moment geregeld is?

Voordelen: Eigenlijk niks. Er is wel veel flexibiliteit om alles te doen op dit moment.

Nadelen: Het is niet geregeld, ongecontroleerd. We weten niet wat er aankomt waar het aankomt. We gebruiken veel meer ruimte en capaciteit dan dat er nodig is.

Grootste reden waarom de logistiek op het moment aangepast moet worden?

Het kan slimmer en efficiënter. Door meer efficiency komt er minder chaos en een veiligere situatie. Niet onbelangrijk het voorkomen van overlast voor de buurt. De RAI is nu volgend en zou meer een sturende rol moeten hebben in de logistiek.

Wat zijn de eisen waar de nieuwe logistiek aan moet voldoen?

Inzicht hebben in wat wanneer voor de poort verschijnt en daar controle over kunnen uitoefenen. Georganiseerd gestructureerd, zuinig, schoon, stil en uiteindelijk deels geautomatiseerd. Op het moment is het een push systeem en het moet meer een pull systeem worden. Vanaf de beursvloer afroep wat er moet doorkomen.

Wat zou je zelf graag veranderd zien in de logistiek?

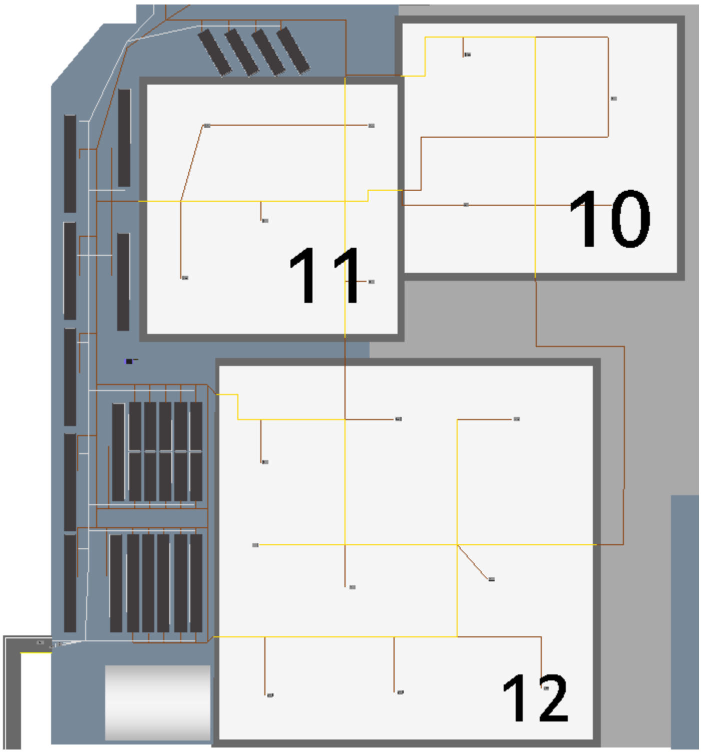
Logistiek op de zuidzijde blijft het zelfde maar met stillere voertuigen. Een volledige ontkoppeling van bezoekersverkeer en logistiek verkeer. Vanaf zuid met een tunnel naar noord waar een logistieke ruimte is onder hal 7. Vanuit hal 7 vervolgens goederen vervoeren naar de eind hal.

D | Model Lay-out

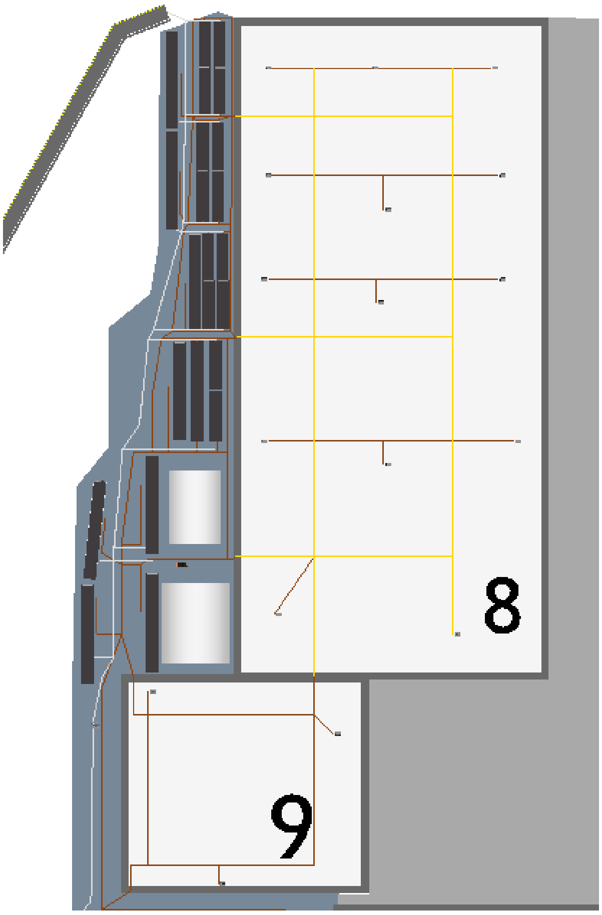
A more detailed overview of the lay out of the current situation model is given. In Figure D.1 an overview is given of the work sites P5A and P5B, which are located on the south side. In Figure D.2 the lay out of the work sites P8, P9 and P10 is shown.

The lay-out consists of different parts the most important aspects of the lay-out are:

- work sites: The work sites can be recognized by the dark grey/blue colour. The RAI has five work sites the P5A, P5B, P8, P9 and P10
- Unloading spots: Spots used by trucks and trailers for unloading. Can be recognized by the black rectangles. There are two types of unloading spots, dedicated spots for trailers and for trucks. The longer rectangles are mainly used by trailers and the smaller rectangles by trucks only
- Transport network for trucks and trailers: Within the model trucks and trailers can use the main roads and the grey paths
- Transport network for pallet transportation: Pallets can be transported either with a forklift or by hand. These two options both use the same network. Outside the halls the network can be recognized by the red/brown colour. Within the halls there are two types of paths, yellow and red/brown. The yellow paths have a higher maximum speed limit than the red/brown paths within the halls
- Halls: The halls can be recognized by the white squares and are numbered by the numbering used within the RAI
- Stands within halls: Normally halls are filled with hundreds of stands, however this would make the model too complex and detailed. Therefore, multiple points are constructed within halls that represent multiple stands. Pallets are transported to these points

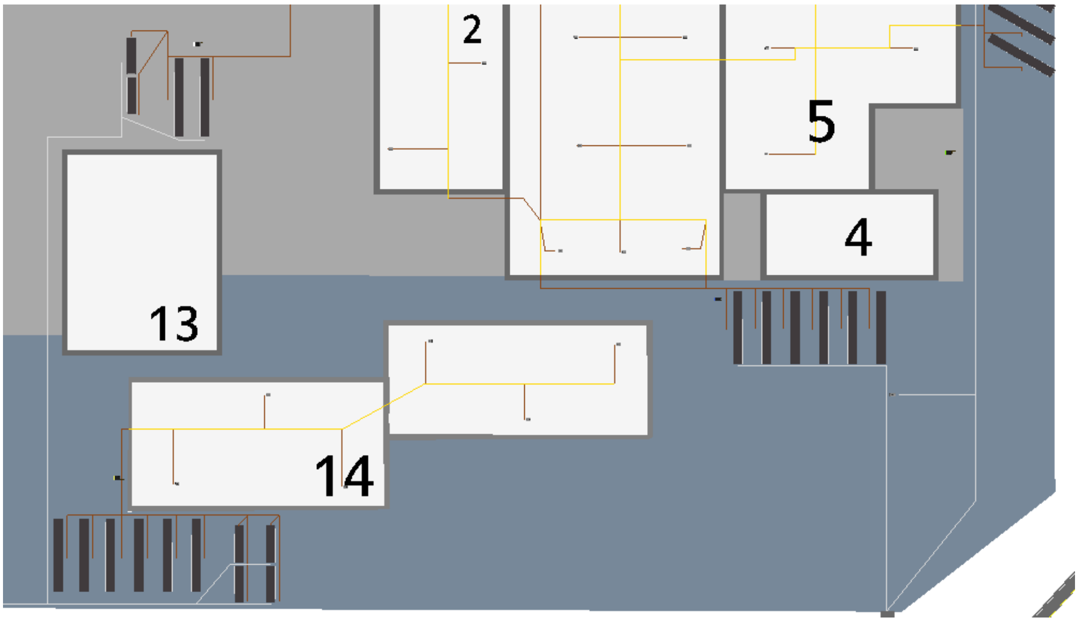


(a) Overview P5A

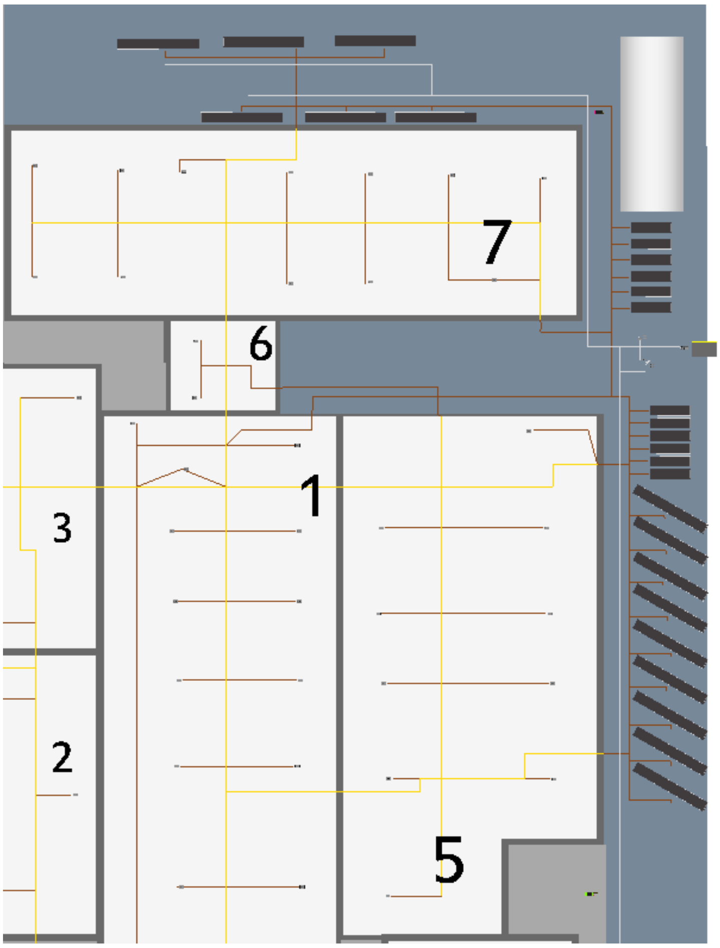


(b) Overview P5B

Figure D.1: Overview south side



(a) Overview P8



(b) Overview P9 & P10

Figure D.2: Overview north side

D.1 Simulation Runs

The precision of the model is influenced by the amount of replications that is run. A high level of replications increases the accuracy; however, it is also more time consuming. There are several methods than can be used to determine the number of runs. These methods try to find the lowest number of runs where the confidence is sufficient. In this research two methods are used: the confidence interval method and the graphical method. The confidence interval method calculates the desired precision and based on this precision a choice can be made on the number of runs. The desired precision is calculated by the following formula:

$$Precision = \frac{\frac{1}{2} * Confidence\ interval}{Cumulative\ mean} * 100\%$$

When the calculated precision is lower than the desired precision the minimum number of replications is found for the desired precision. However after this point five more replications should be made to check if the performance stays below the desired performance. If this is not the case more replications should be run (Hoad, Robinson, & Davies, 2007). In the research of Hoad et al. the desired performance in set on 5%.

The precision level is calculated for 5 output variables, which are the unloading time of self-loading trailers, unloading time logistic partner trailers, unloading times self-loading trucks, unloading times logistic partner trucks and pallet delivery time. The data is obtained from Simio and calculations are made in Excel. In total there are ten scenarios executed with varying replications between 5 and 50. In Table D.1 the calculated performances are shown for seven of the runs. After 25 replications four out of the five variables are below the confidence interval 5%. However, the unload time for logistic partner trucks is above the 5%. It shows that still after 50 replications the performance is still above the 5%. Running sets of 50 replications would be very time consuming. To further investigate the performance a second method, the graphical method, is used.

Table D.1: Calculated performance

	20 replications	25 replications	30 replications	35 replications	40 replications	45 replications	50 replications
Unload trailer LP	5,38	4,80	4,04	3,98	3,70	3,43	3,28
Unload trailer SL	2,61	2,14	2,10	1,92	1,77	1,60	1,52
Unload truck LP	8,37	7,46	6,55	6,08	5,63	5,44	5,37
Unload truck SL	1,22	1,06	0,98	0,96	0,87	0,79	0,76
Pallet delivery time	3,52	3,11	2,67	2,51	2,36	2,16	2,10

With the graphical method the cumulative means of the output variables and the number of replications are visualised within a plot. With the plot insight is given on where the cumulative mean becomes "flat". The point where the cumulative means becomes flat indicates the number of replications that should be used (Hoad et al., 2007).

Since in the prior method the unloading time of the logistic partner did not meet the desired performance this variable will be further inspected. In Figure D.3 the cumulative means of the variables unloading times logistic partner and self-loader are shown. For the self-loader the line becomes flat after 25 replications. The line of the unloading time for the logistic partner is not as flat and varies more. However, the main drop in the cumulative mean is over after 15 runs. After 20 runs there is no big increase or decrease in the mean value.

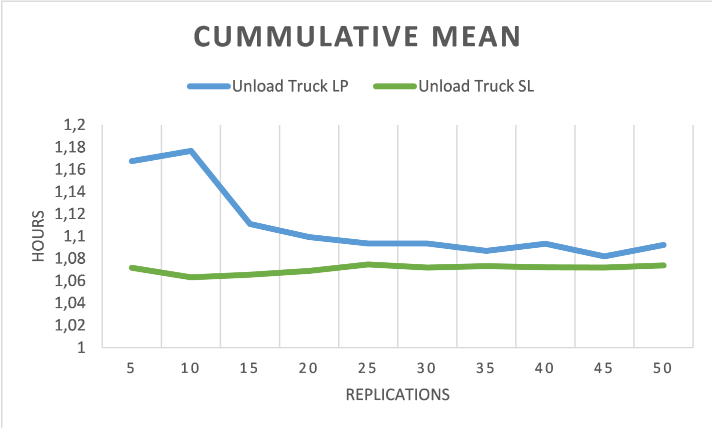


Figure D.3: Cumulative means

With the outcomes of both methods there is decided to set the simulation runs on 25 replications. The desired confidence for the unloading time of a truck logistic partner did not meet the requirement. However, after visualizing the cumulative mean and not seeing major differences the decision has been made to stick with 25 replications. Increasing the amount above 50 replications to achieve the desired performance would highly increase the running time of the model. Four out of the five variables met the desired performance after 25 runs and no major differences were seen in the cumulative means of the one other variable. Therefore, the decision is made to stick with the 25 replications.

E Model Parameters

E.1 Parameters Current Situation

In the following tables the different parameters of the current situation simulation model are given. Table E.1 shows the number of unloading spots at the different work sites. Table E.2 and Table E.3 give the share of the amount of pallets per truck or trailer and the share of self-loaders. These values are based on estimations made by the RAI. Table E.4 shows the forklift parameters. The speeds are based on measurements and the number of forklifts is based on information obtained from the logistic partner of the RAI. Table 4.1 shows the unloading time values. These values are based on conducted measurements. And Table E.6 shows the truck and trailer speed and registration time. The registration time is based on measurements obtained from the measuring experiment.

Table E.1: work site unloading spots

Unloading spots	Truck	Trailer
P5A	24	9
P5B	16	8
P8	6	14
P9	6	9
P10	6	6

Table E.2: Pallet share trucks and trailers

Number of pallets	5	10	15	20
Truck	30%	60%	10%	0%
Trailer	10%	30%	30%	30%

Table E.3: Self-loader and logistic partner share trucks and trailers

Share self-loader	Self-loader	Logistic partner
Trailer	20%	80%
Truck	70%	30%

Table E.4: Forklift parameters

Forklifts		
Speed outside hall	5	Km/h
Speed near truck/trailer	2.5	Km/h
Speed within hall	Random.Uniform(1.5,4.2)	Km/h
Max speed non-yellow path in hall	2.5	Km/h
Number of forklifts	40	

Table E.5: Unloading times

Unloading times		
Time before truck/trailer starts unloading	Random.Uniform(1,15)	Minutes
Time to unload pallet from truck on forklift	Random.Uniform(30,240)	Seconds
Time to unload pallet from forklift on floor	Random.Uniform(30,60)	Seconds
Unloading time self-loader	Random.Uniform(1.5,12)	Minutes

Table E.6: Truck and trailer speed

Trucks/trailers		
Registration time at RAI entrance	Random.Uniform(0.5,2)	Minutes
Speed on work site	5	Km/h
Speed on main road	35	Km/h
Speed on connecting road	10	Km/h

E.2 Parameters Design Alternatives

The design alternatives have similar en different parameters compared to the simulation model of the current situation. In the tables below the parameters are shown that differ or are new compared to the current simulation model. Table E.7, E.8 and E.9 show parameters, which are used in all five designs. The number of unloading spots, forklifts and EPTs are similar for every designs alternative. Table E.10, E.11 and E.12 shows the parameters specific for the particular design alternative. These parameters are only used in this specific design alternative.

Table E.7: Unloading spots within design alternatives

Unloading spots	Truck	Trailer
P5A	24	9
P5B	16	8
NLN	6	7

Table E.8: Number of forklifts and EPTs in design alternatives

Number of Forklifts/EPTs	Forklift	EPT
P5A	6	12
P5B	6	9
NLN	15	50

Table E.9: Unloading times in design alternatives

Unloading times		
EPT pallet load time	Random.Uniform(30,60)	Seconds
EPT pallet unload time	Random.Uniform(30,60)	Seconds
EPT speed in tunnel	9	km/h

Table E.10: Parameters for design 3

Design 3		
Conveyor belt speed	2	Km/h
Number forklifts to load conveyors	3	
Number forklifts to unload conveyors	3	
Time to put pallet on conveyor	Random.Uniform(20,30)	Seconds
Time to take pallet of conveyor	Random.Uniform(20,30)	Seconds

Table E.11: Parameters for design 4

Design 4		
Number of RGVs	20	
Loading time pallet on RGV	Random.Uniform(10,30)	Seconds
Unloading time pallet of RGV	Random.Uniform(10,30)	Seconds
RGV speed	10	Km/h
Unloading time forklifts at RGV loading station	Random.Uniform(20,30)	Seconds
Number of loading docks	4	

Table E.12: Parameters for design 5

Design 5		
Number of AGVs	25	
Loading time pallet on AGV	Random.Uniform(30,60)	Seconds
Unloading time pallet of AGV	Random.Uniform(30,60)	Seconds
AGV speed	7	Km/h
Unloading time forklifts at AGV loading spot	Radom.Uniform(30,60)	Seconds
Number of loading docks	4	

F | Data Generation

The RAI has limited data available, which means that data had to be generated to represent different scenarios. The idea is that new data is generated based on the patterns of the original data set. This means that the patterns of the existing data set are transferred to a new data set. The new generated data sets differ on the number of trucks and trailers. With these new generated data sets other scenarios can be simulated such as a very calm, normal or even busier day. The pattern that should remain the same is the destination of trucks and trailers and the share of truck or trailers.

The easiest way to generate new data is by applying a random uniform distribution. When applying this distribution every destination has the same chance of being chosen. To determine if the data is uniformly distributed a check was performed with SPSS. The outcomes showed that the data is not uniformly distributed. Other distributions were also checked with SPSS but no distribution was found.

Since no clear distribution was found the new generated data is generated based on probabilities. To determine the probabilities first the frequencies of certain combinations in the data were generated with SPSS, the outcomes can be found in Figure F.1. In the left column the possible combinations are shown. The first number stands for either a truck or trailer and the second number for a destination. For example 13 stands for a trailer that goes to destination 3 (work site P8) and 26 stands for a truck with destination 6 (work site P10).

Frequencies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	11,00	136	8,4	8,4	8,4
	12,00	96	5,9	5,9	14,3
	13,00	51	3,1	3,1	17,4
	14,00	188	11,5	11,5	28,9
	15,00	62	3,8	3,8	32,7
	16,00	99	6,1	6,1	38,8
	21,00	211	13,0	13,0	51,8
	22,00	198	12,2	12,2	63,9
	23,00	58	3,6	3,6	67,5
	25,00	352	21,6	21,6	89,1
	26,00	177	10,9	10,9	100,0
	Total	1628	100,0	100,0	

Figure F.1: Frequencies data generation

With the frequencies the probabilities could be calculated by dividing the frequency with the total. This would mean that the probability for combination 11 is: $probability = \frac{136}{1628}$. These probabilities are calculated for every combination and after this the cumulative probability can be calculated. These cumulative probabilities are also shown inFigure F.1 as the cumulative percent.

Next Excel was used to draw a set of random numbers, which are distributed uniformly. If the random number lies within the cumulative probability of a certain combination this number resembles this combination. This results in the set of random numbers being represented as truck, trailer and destination combinations. By choosing the amount of random numbers the number of combinations can be influenced. In this way a set of 10 trucks and trailers can be generated or even a set of 1000 trucks and trailers without losing the patterns from the original data set.

G | Experimental Plan

In order to test different set-ups and technologies experiments are performed. Within this research two different experiments are used. The first experiment is used to determine the effects of the general changes: truck appointment system, extending operational time and cross-docking. The second experiment is used to see how the different designs behave.

G.1 Experimental Plan: Strategies

In order to see the effect of the main strategies they are implemented in the simulation model of the current situation. If the outcomes show that they improve the performance the decision is made to implement them in the designs. In Table G.1 the different scenarios for the experiment can be seen. To get a good overview of the effects every possible combination of, arrivals, truck appointment system and operational time is run. This means that for the scenario with 160 arrivals 6 combinations are run, and for the 280 and 400 arrivals as well. In total 18 scenarios have been run.

After the experiment with the truck appointment system and extended operational time cross-docking is researched. The current simulation model was adapted to a cross-docking situation. And the different arrival set ups: 160, 280 and 400 are run with the cross-docking set-up. Finally a combination of cross-docking, peak-shaving and operation time is researched. This means that the 18 scenarios used for peak-shaving and operational time are also run in the model with the cross-docking set-up.

Table G.1: General changes scenarios

Arrivals	Peak-shaving	Operational time	Cross-docking
160/280/400 trucks & trailers	1 hour/15 minutes	12/14/16 hours	Yes/No

G.2 Experimental Plan: Designs

To see how the different design influence performance an experiment is used. Within this experiment there is assumed that cross-docking is used and the time-slot in the truck appointment system are constant. For every design 9 scenario are run. These scenarios differ on arrivals and operational time. The same options are used as in the experiment for the general changes. This means arrivals of 160, 280 and 400 trucks and trailers, and an operational time of 12, 14 or 16 hours.

H Strategies Outputs

H.1 Truck Appointment System and Operational Time

To see the effect of peak-shaving and increasing operational time different scenarios are run for three different situations. The three situations are 160 truck & trailer (Table H.2, 280 trucks & trailers (Table H.1 and 400 trucks & trailers (Table H.3. The situation with 280 trucks also includes the base scenario which is based on the real data. Each scenario is run 25 times.

As can be seen in the situation with 280 trucks & trailers is that a truck appointment system reduces the unloading times for logistic partner users and the waiting times. The waiting times decrease and if the operational time is extended they decrease even further. However, changing the time-slots from an hour to 15 minutes has no noticeable effect.

Table H.1: Truck Appointment System & Operational time: Outputs 280 trucks & trailers

		Unloading time (min)				Waiting time (min)
	Operational time (hours)	Trailer SL	Trailer LP	Truck SL	Truck LP	
Base		98	92	64	66	16.9
Time-slots						
Hour	12	101	61	64	44	0.2
15 Minutes	12	100	61	65	45	0.3
Hour	14	97	59	64	41	0.2
15 Minutes	14	101	57	64	42	0.2
Hour	16	102	56	64	40	0.2
15 Minutes	16	98	54	64	39	0.2

In the situation with 160 trucks & trailers the unloading and waiting times hardly differ between the scenarios. This can be explained by the fact that there are less trucks and trailers coming in at certain time-slots. Within the unloading times we see a slight decrease if operational time is increased.

Table H.2: Truck Appointment System & Operational time: Outputs 160 trucks & trailers

		Unloading time (min)				Waiting time (min)
	Operational time (hours)	Trailer SL	Trailer LP	Truck SL	Truck LP	
Base		100	69	64	43	1.4
Time-slots						
Hour	12	99	54	64	37	0.2
15 Minutes	12	100	54	65	36	0.2
Hour	14	101	52	65	35	0.2
15 Minutes	14	98	52	64	35	0.2
Hour	16	98	51	65	35	0.2
15 Minutes	16	99	51	64	35	0.2

In the last situation with 400 trucks & trailers larger differences are seen also between the one hour and 15 minutes slots variants. If the time-slots are changed from one hour to 15 minutes we see decreases in unloading and waiting times. Extending the operational time from 12 to 16 hours decreases the waiting time with 27 minutes.

Table H.3: Truck Appointment System & Operational time: Outputs 400 trucks & trailers

	Operational time (hours)	Unloading time (min)				Waiting time (min)
		Trailer SL	Trailer LP	Truck SL	Truck LP	
Base		98	92	65	53	82.6
Time-slots						
Hour	12	101	95	65	68	33.1
15 Minutes	12	101	89	65	61	32.4
Hour	14	99	82	64	52	15.5
15 Minutes	14	99	79	64	49	11.1
Hour	16	97	72	64	48	5.7
15 Minutes	16	98	69	64	45	2.8

H.2 Cross-docking

When cross-docking is applied all work site need buffer space to store pallet temporarily. The space needed for these buffers depends on the maximum number of pallets within the buffer. In Table H.4 the maximum number of pallets is shown for the cross-docking scenarios. In Table H.5 the maximum number of pallets in the buffers is shown for the combination of cross-docking, extending operational times and cross-docking.

Table H.4: Number of pallets in buffers cross-docking, 280 trucks & trailers

# Forklifts	# EPTS	# Pallet in buffer					
		P8A	P8B	P9	P10	P5A	P5B
40	20	92	114	107	123	209	203
20	20	26	89	91	111	114	112
40	40	54	54	71	37	73	68
20	40	4	8	7	5	4	6

Table H.5: Number of pallets in buffers cross-docking & truck appointment system, 280 trucks & trailers

# Forklifts	# EPTS	# Pallets in buffer					
		P8A	P8B	P9	P10	P5A	P5B
40	20	50	31	43	65	68	91
20	20	17	30	48	42	59	59
40	40	27	13	29	18	17	27
20	40	4	8	6	3	5	5

I Conceptual Models Designs

For the different designs conceptual models are made to get a better overview of the processes involved in each design. The created simulation models of the designs are based on the conceptual models.

I.1 Conceptual model design 1

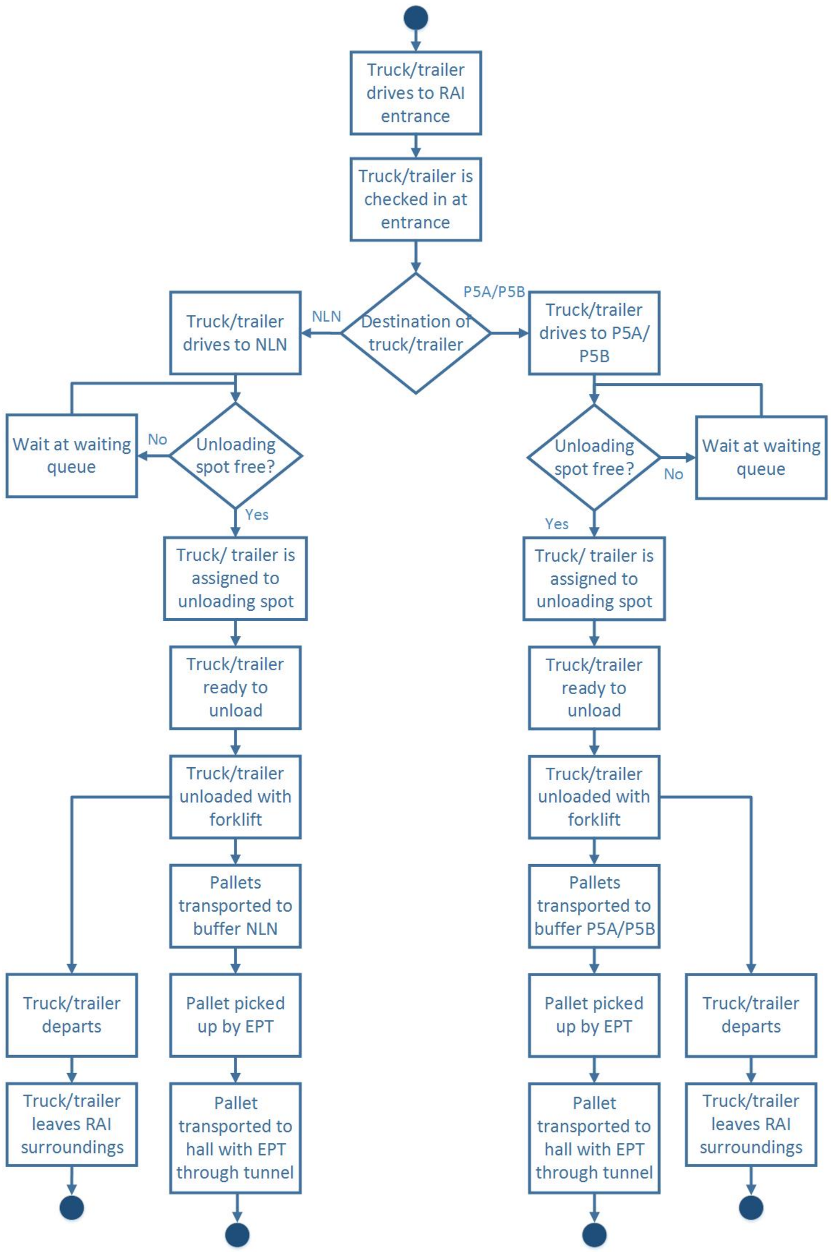


Figure I.1: Conceptual model design 1

I.2 Conceptual model design 2

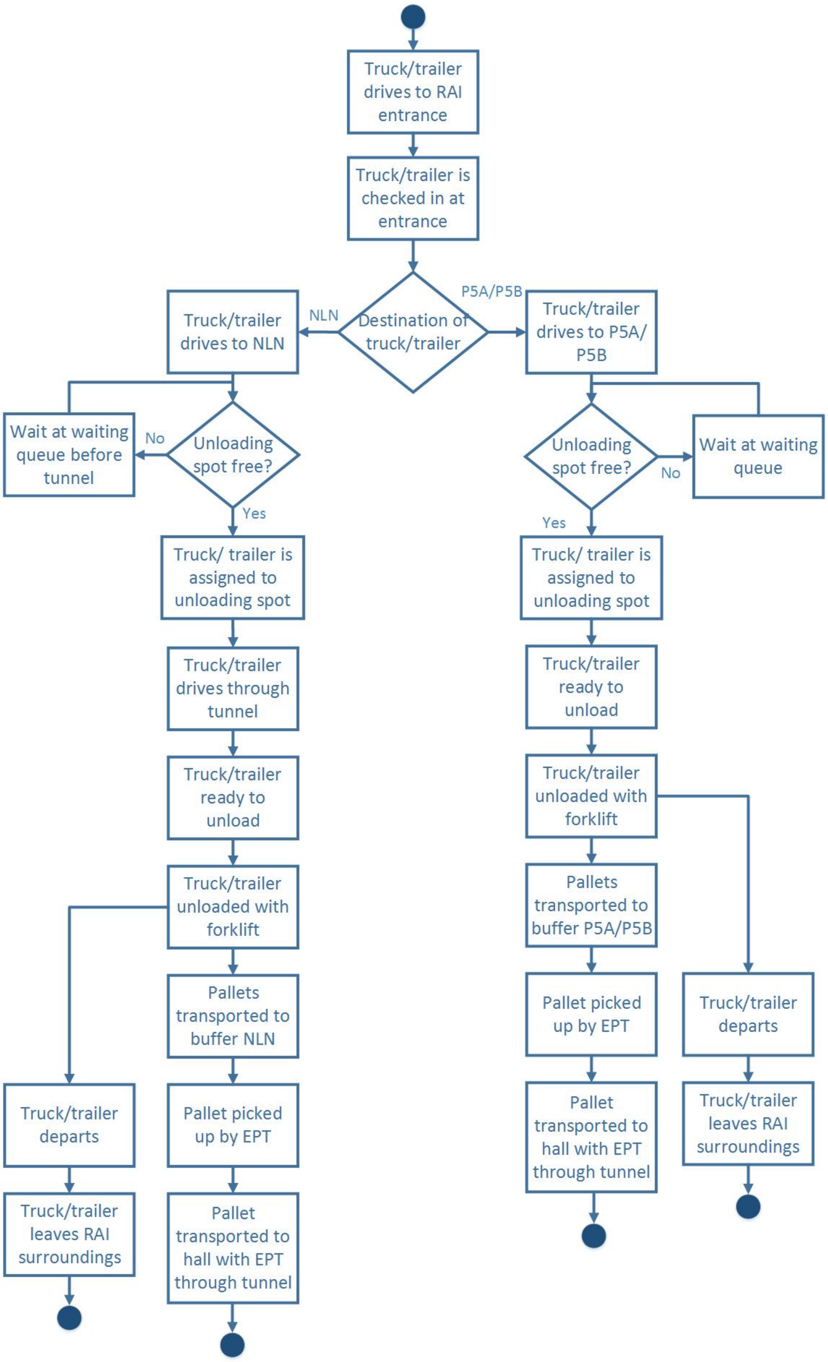


Figure I.2: Conceptual model design 2

I.3 Conceptual model design 3

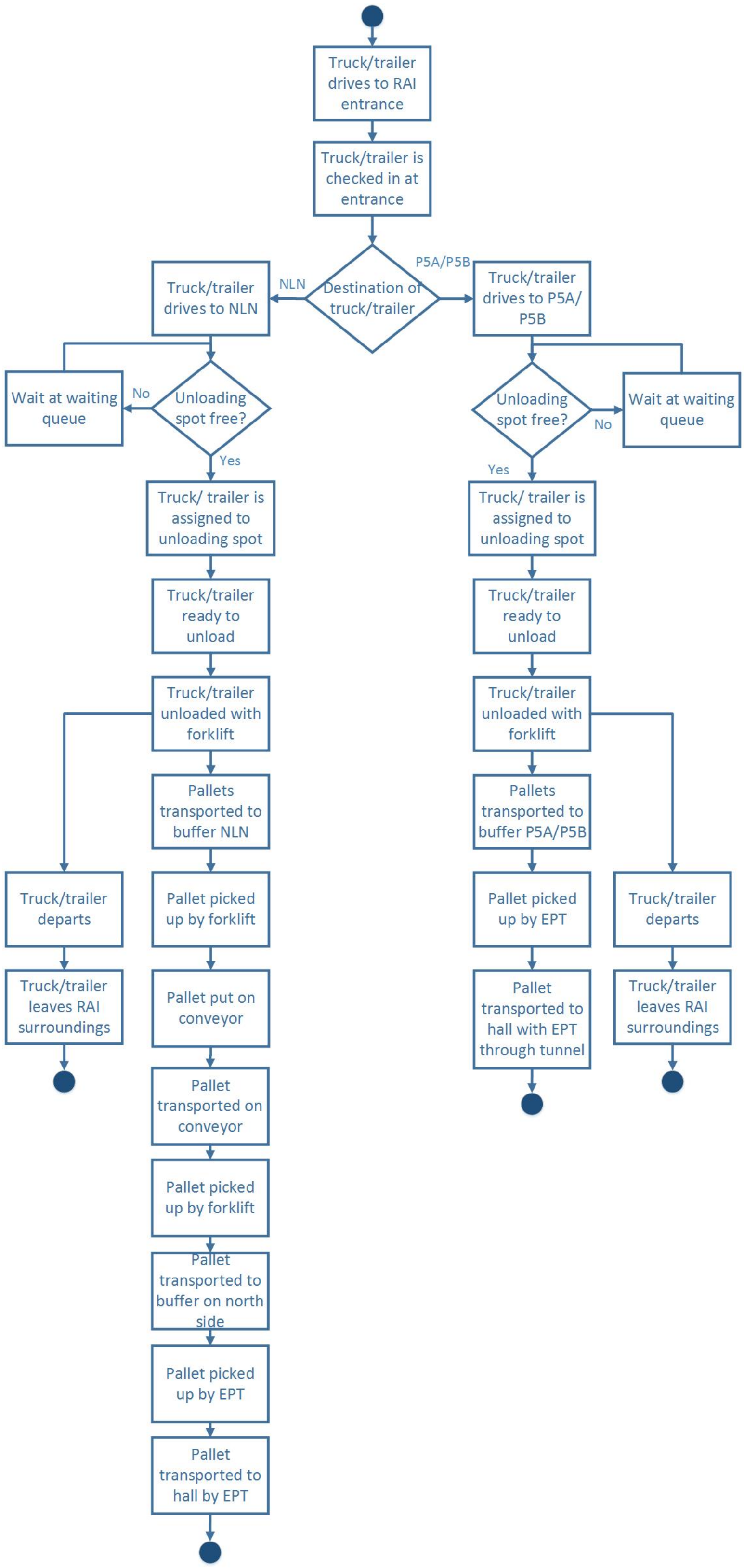


Figure I.3: Conceptual model design 3

I.4 Conceptual model design 4

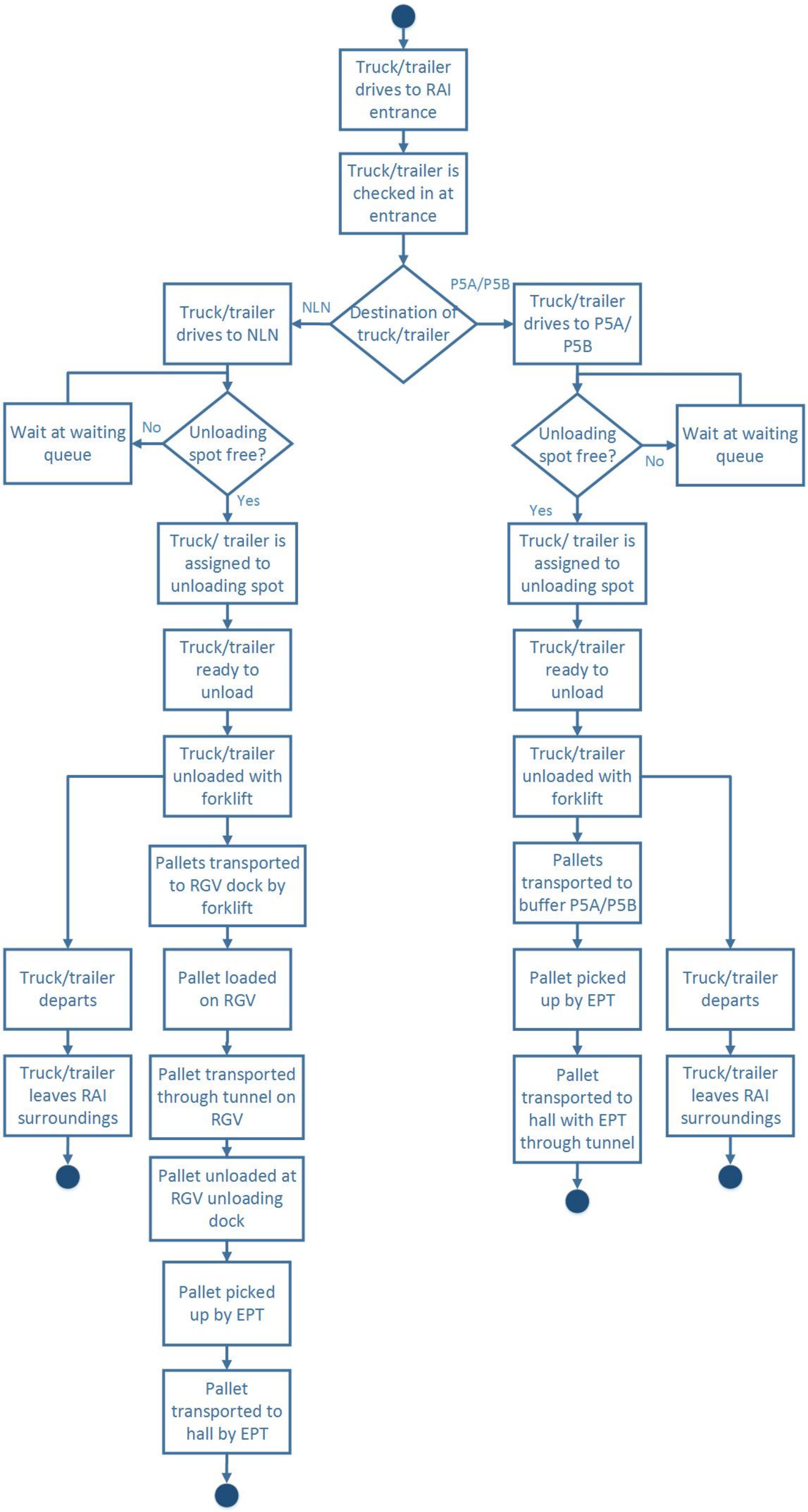


Figure I.4: Conceptual model design 4

I.5 Conceptual model design 5

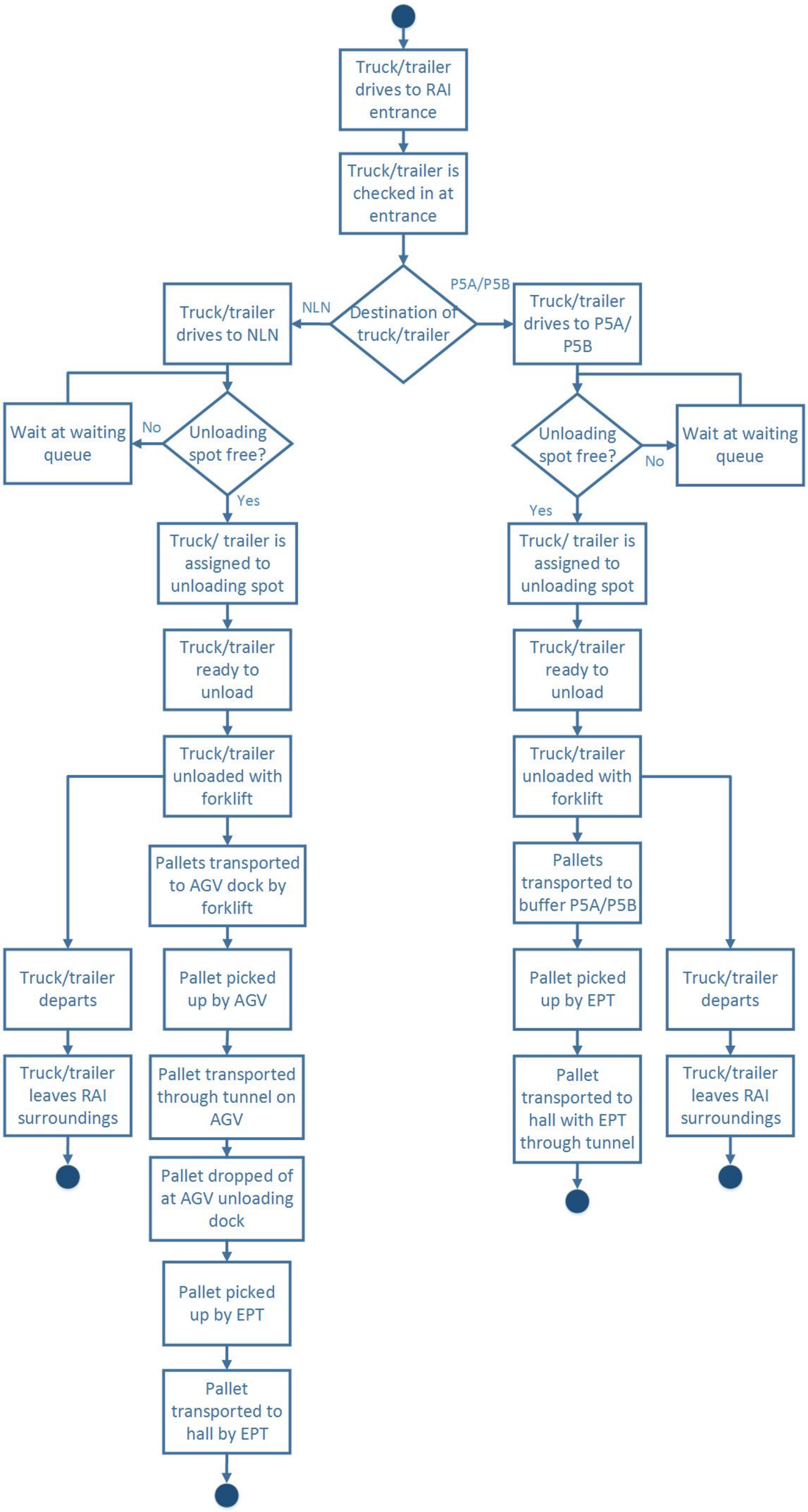


Figure I.5: Conceptual model design 5

J | Designs in Simio

The designs have been simulated with the program Simio. To get a good understanding of how designs look like in the simulation program several examples of the designs are shown.

J.1 Design 1

In Figure J.1 the layout of the NLN of Design 1 is shown. For designs 3,4 and 5 the similar layout of the NLN is used. The NLN is constructed at the south side partly underneath the work site of the P5B. In Figure J.2 the buffer and the tunnel can be seen. The buffer is the area where the pallets are stored. The forklifts drop the pallets here and the EPTs picked them up. After the pick-up the EPT drives through the tunnel to the north side.

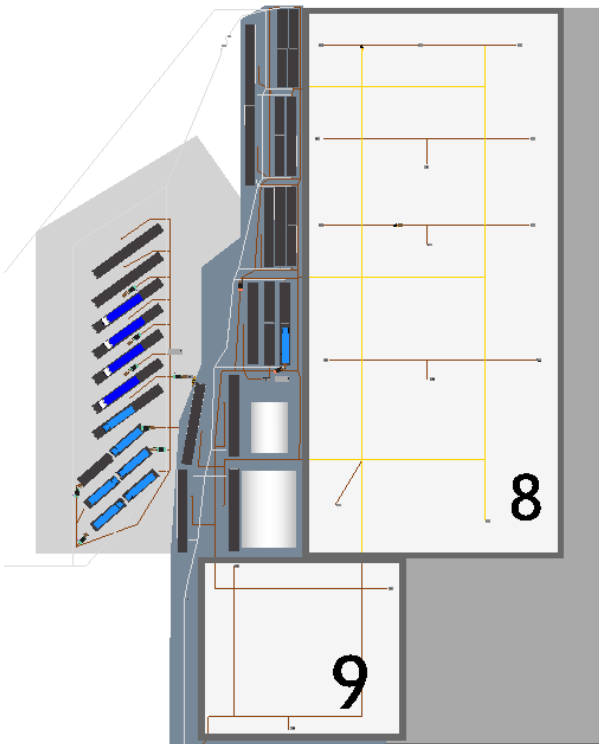


Figure J.1: Overview of NLN Design 1

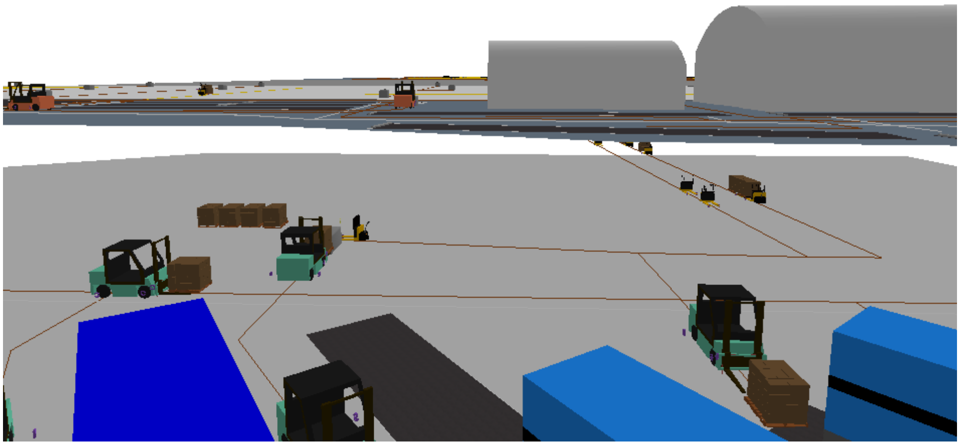


Figure J.2: Overview of buffer and tunnel design 1

J.2 Design 2

In Figure J.3 the NLN of design 2 is shown. The NLN is located underneath hall 7. This picture also shows a trailer waiting on the left side to enter the NLN. If there are no available unloading spots trucks and trailers have to wait before the tunnel. To give a good visualization the floor of hall 7 has been removed. This way the NLN is visible. In Figure J.4 an more detailed view of the NLN is given. The buffer of pallets is visible. The EPTs pick up the pallet and drive to hall level, this path is visible on the left side.

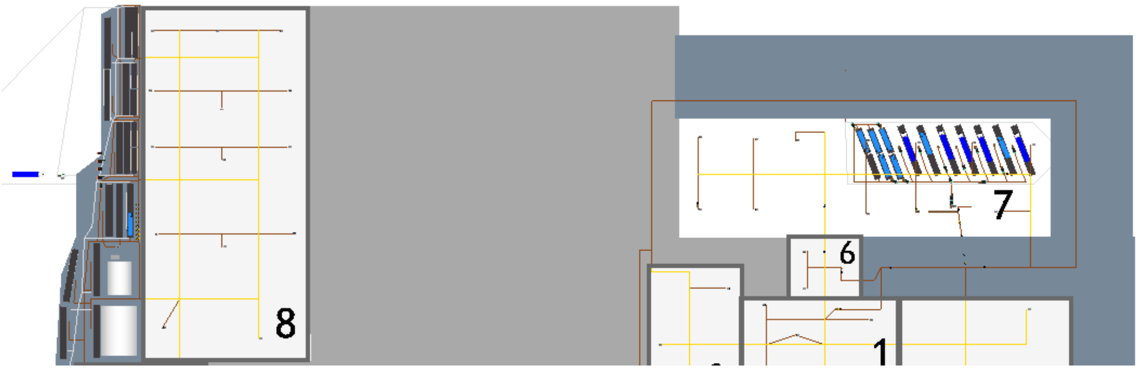


Figure J.3: Overview of NLN design 2

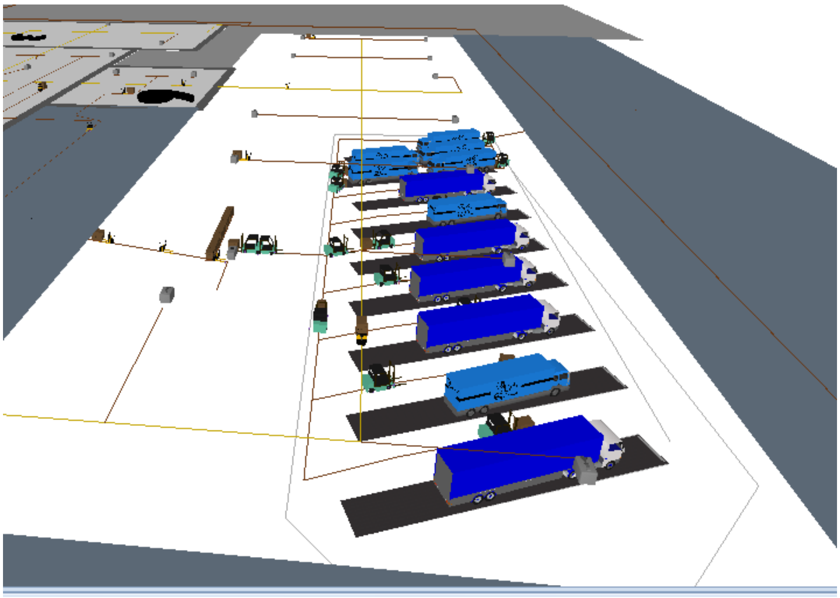


Figure J.4: Overview buffer at NLN design 2

J.3 Design 3

In this design the NLN has the same lay-out as design 1 Figure J.1. Figure J.5 shows the overview of the NLN of design 3. It shows the buffer and the start of the conveyors on the south side. The yellow forklifts have the task to put the pallets on the conveyor and the blue forklifts unload the trucks and trailers. In Figure J.6 the end of the conveyors are shown. The conveyors end after hall 6, which is in the space between hall 7 and 1. This end is still constructed under the hall. The forklifts pick-up the pallet from the conveyor and drop them at a buffer area. Here the EPTs pick-up the pallets and drive to hall level and deliver them to the stand.

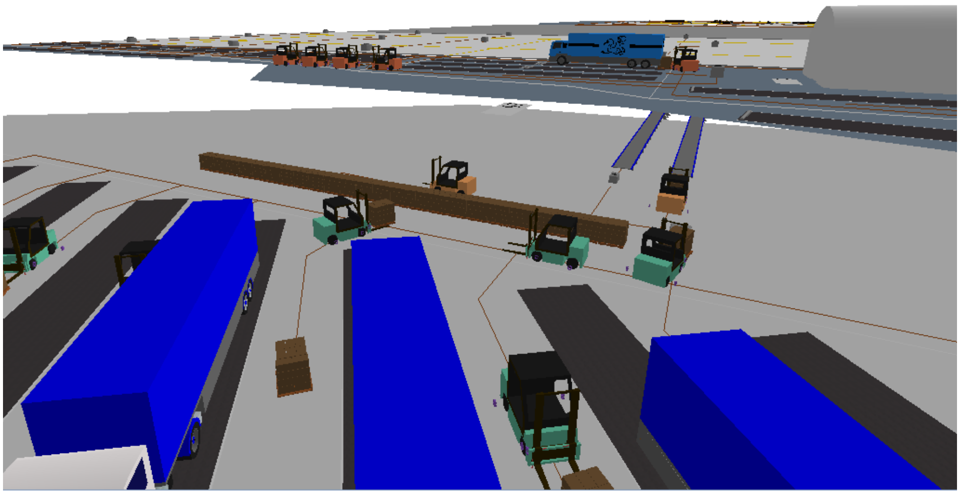


Figure J.5: Overview of buffer and conveyor design 3

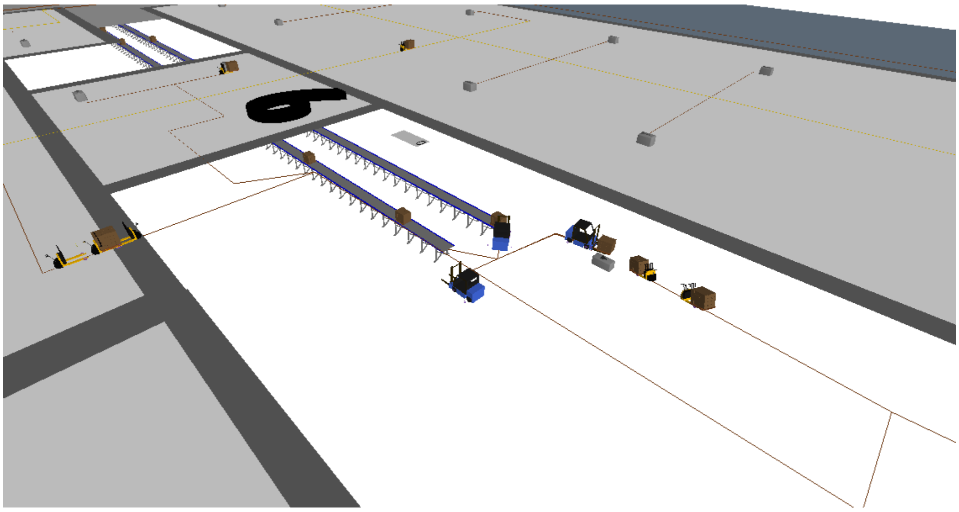


Figure J.6: Overview of end of conveyor north side design 3

J.4 Design 4

In this design the NLN has the same lay-out as design 1 Figure J.1. Figure J.7 shows an overview of the NLN. The forklifts drop the pallets of at the automatic loading stations of the RGVs. The RGVs pick-up the pallets and bring them to the north side. In Figure J.8 the end of the RGV track is shown. The pallets are automatically unloaded from the RGV and the pallet is picked up by the EPT. The EPT brings it to the final destination. The end of the RGV track ends after hall 6, between halls 7 and 1. The RGV system is completely build under the RAI. This means that the EPTs have to use a ramp to get there.

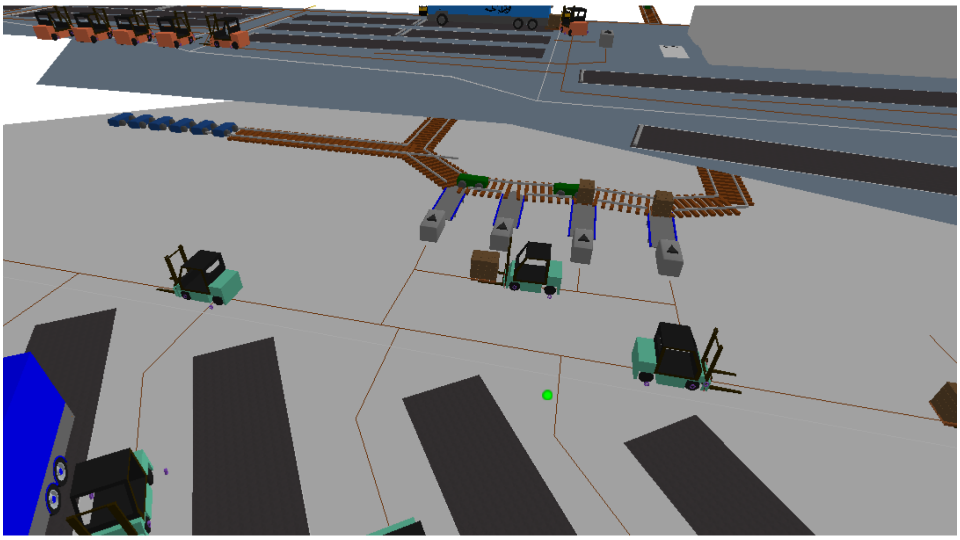


Figure J.7: Overview of buffer and RGV design 4

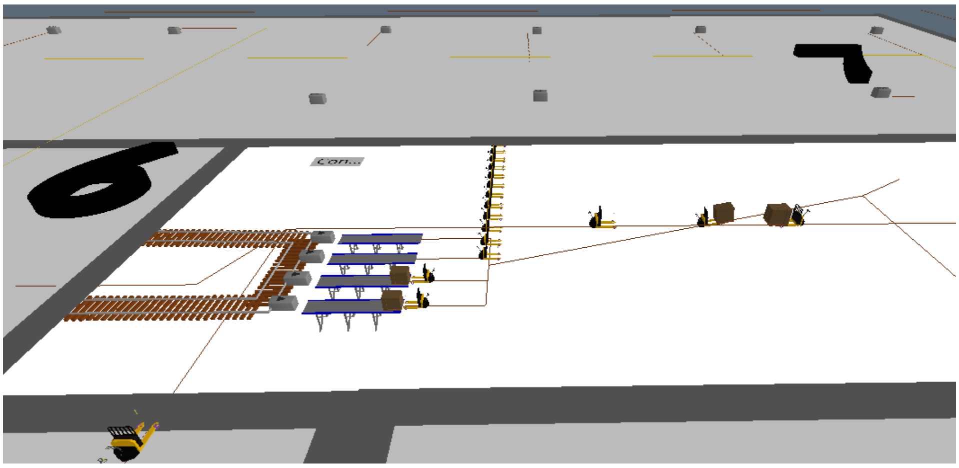


Figure J.8: Overview of end of RGV north side design 4

J.5 Design 5

In this design the NLN has the same lay-out as design 1 Figure J.1. Figure J.9 shows the overview of the buffer and the AGV system. Forklifts drop the pallets at the pick-up lines. AGVs drive to these pick-up points to pick-up the pallet. The pallet is transported on the AGV to the north side. The AGV system at the north side is shown in Figure J.10. At the north side the AGV drops the pallet at a pick-up line. EPTs pick-up the pallets and transports the pallet to the final destination. The end of the AGV track is located between halls 7 and 1. The AGV system is completely build under the RAI. This means that the EPTs have to use a ramp to get there.

Figure J.9: Overview of buffer and AGV design 5

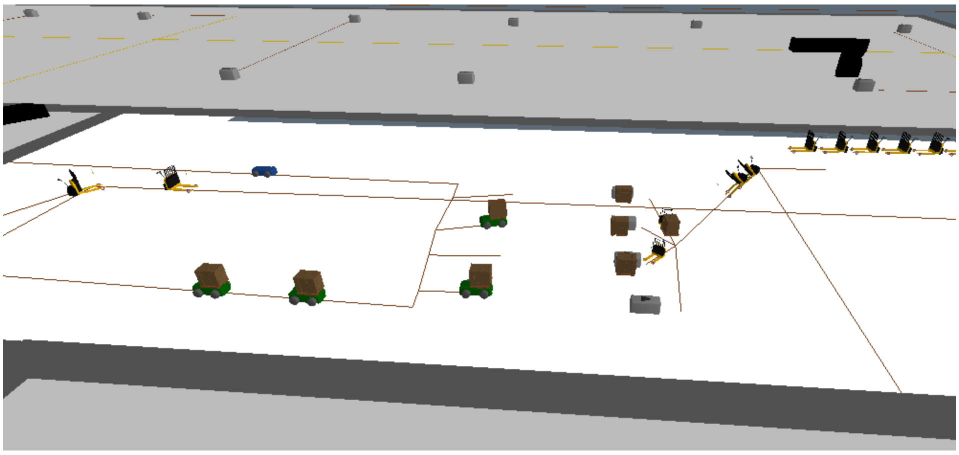


Figure J.10: Overview of end of AGV north side design 5

K | Simulation Results

The simulation experiment consists of 3 different arrival patterns: 160, 280 and 400 trucks and trailers. Every arrival pattern is run with different operational times: 12, 14 and 16 hours. The outcomes of the arrival pattern with 160 vehicles can be seen in Table K.1. Table K.2 shows the outcomes of the arrival with 280 trucks and trailers and Table K.3 of 400 trucks and trailers.

Table K.1: Simulation outcomes 160 vehicles

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Current	53.3	84.2	53.3	84.2	53.3	84.2	0.0	1.4	43.4	0	40	0
Operational time 12 hours												
Design 1	30.9	48.2	30.5	45.1	30.3	46.5	0.0	0.0	31.1	27	41	0
Design 2	32.3	47.7	29.9	46.7	31.0	46.2	0.0	0.0	27.7	23	27	0
Design 3	31.8	48.3	30.0	46.8	31.1	46.3	0.0	0.0	47.0	53	18	6
Design 4	31.6	48.3	29.4	46.6	30.5	45.4	0.0	0.0	30.1	13	25	15
Design 5	31.8	46.8	29.7	46.1	30.6	45.7	0.0	0.0	31.3	12	26	22
Operational time 14 hours												
Design 1	30.6	48.8	32.0	44.8	31.0	46.5	0.0	0.0	31.1	23	36	0
Design 2	31.5	48.0	29.9	45.7	30.8	45.5	0.0	0.0	27.5	18	27	0
Design 3	31.5	47.2	30.3	45.1	30.8	45.7	0.0	0.0	42.7	42	18	6
Design 4	31.9	48.1	30.5	47.2	30.6	45.0	0.0	0.0	30.0	10	28	15
Design 5	32.3	48.1	30.6	45.8	31.1	45.8	0.0	0.0	31.3	14	25	21
Operational time 16 hours												
Design 1	31.8	47.9	29.7	47.1	30.8	46.1	0.0	0.0	31.0	15	34	0
Design 2	31.7	47.9	29.3	47.0	30.9	45.2	0.0	0.0	27.3	16	23	0
Design 3	31.8	47.6	30.1	46.7	30.6	46.0	0.0	0.0	41.8	40	17	6
Design 4	30.6	49.9	30.1	47.3	31.1	45.4	0.0	0.0	30.2	9	24	15
Design 5	32.1	47.3	30.0	46.7	31.2	45.8	0.0	0.0	31.3	8	22	19

Table K.2: Simulation outcomes 280 vehicles

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Current	65.1	94.7	65.1	94.7	65.1	94.7	0.0	16.9	51.5	0	40	0
Operational time 12 hours												
Design 1	36.9	51.8	31.9	50.4	32.4	48.8	0.0	1.1	47.0	228	50	0
Design 2	36.6	52.4	31.7	48.9	33.8	49.3	0.0	7.3	29.9	54	34	0
Design 3	36.5	52.6	31.7	50.0	32.0	48.4	0.0	0.9	117.8	562	20	6
Design 4	36.9	51.5	32.1	50.2	32.0	47.4	0.0	0.6	32.1	61	32	18
Design 5	37.1	52.1	31.6	50.4	33.3	47.8	0.0	1.0	33.2	48	32	27
Operational time 14 hours												
Design 1	32.9	48.9	31.2	49.3	31.4	47.3	0.0	0.1	34.2	125	50	0
Design 2	32.2	48.7	30.6	49.9	32.7	46.6	0.0	0.9	27.9	48	31	0
Design 3	32.3	48.3	30.1	49.3	31.3	47.9	0.0	0.2	77.1	284	20	6
Design 4	33.1	48.1	30.8	47.2	31.3	47.0	0.0	0.1	30.2	36	33	19
Design 5	32.7	48.2	30.3	48.5	31.6	46.5	0.0	0.0	31.1	46	29	25
Operational time 16 hours												
Design 1	31.6	48.2	30.4	49.2	31.1	46.9	0.0	0.0	31.3	93	50	0
Design 2	33.6	50.1	30.6	46.5	32.1	47.2	0.0	0.4	28.1	62	29	0
Design 3	31.2	46.7	29.9	48.8	30.9	47.4	0.0	0.0	56.6	160	21	6
Design 4	32.2	47.8	30.5	47.7	31.0	46.3	0.0	0.0	29.6	28	29	17
Design 5	31.5	47.4	30.6	47.7	31.1	46.0	0.0	0.0	30.5	30	27	24

Table K.3: Simulation outcomes 400 vehicles

	Unloading times [min]						Waiting times [min]		Delivery time [min]	Total buffer size [# pallets]	Used EPTs [# EPTs]	Number of other vehicles [# vehicles]
	P5A		P5B		NLN		P5	NLN				
	Truck	Trailer	Truck	Trailer	Truck	Trailer						
Current	58.8	95.1	58.8	95.1	58.8	95.1	0.0	79.7	50.8	0	40	0
Operational time 12 hours												
Design 1	59.8	84.6	30.9	49.5	34.4	54.0	0.0	83.4	135.4	876.0	50.0	0.0
Design 2	62.2	88.0	30.2	48.6	33.6	52.8	0.0	172.9	37.9	51.0	32.0	0.0
Design 3	56.8	80.3	30.1	47.6	34.0	53.2	0.0	79.1	185.6	1302.0	20.0	6.0
Design 4	56.5	81.9	30.6	47.8	34.8	53.2	0.0	88.3	41.4	54.0	33.0	19.0
Design 5	57.1	81.2	30.6	50.4	36.7	54.6	0.1	109.0	42.0	44.0	32.0	28.0
Operational time 14 hours												
Design 1	36.2	54.2	30.1	48.4	34.6	51.4	0.0	12.3	124.518	857	50	0
Design 2	36.3	54.3	29.8	47.7	34.1	52.4	0.0	131.5	30.69	48	34	0
Design 3	36.7	55.4	30.1	48.6	34.4	51.1	0.0	9.0	175.302	1277	21	6
Design 4	35.8	55.6	30.2	47.7	34.7	50.2	0.0	11.7	34.56	40	33	19
Design 5	35.4	54.7	30.7	49.3	36.7	54.1	0.0	33.8	35.844	37	32	28
Operational time 16 hours												
Design 1	33.0	51.3	30.3	47.8	32.4	48.7	0.0	2.4	94.3	597	50	0
Design 2	32.9	49.6	29.9	47.2	34.3	51.9	0.0	48.5	29.7	46	34	0
Design 3	33.0	51.1	30.1	48.1	32.3	48.9	0.0	2.2	155.9	1052	20	6
Design 4	33.4	50.9	29.8	46.9	32.2	47.6	0.0	1.8	31.6	37	34	18
Design 5	33.2	50.2	30.4	46.5	34.5	49.5	0.0	2.7	33.3	29	31	27

L | AHP Matrices

L.1 Pairwise Comparison Matrices

To get an good overall overview three persons were asked to perform the pairwise comparison. These are the manager of the traffic department (Table L.1). the interim manager (Table L.2) and a traffic manager (Table L.2). Their pairwise comparison matrices are shown in the tables below. The pairwise comparison is done with number ranging from 1 to 9. A 9 means that the criteria is much more important than the other criteria and a 1 means that they are equally important.

Table L.1: Pairwise comparison matrix: Manager traffic department

	Unloading time	Waiting time	Delivery time	Space	Costs	Number of EPTs	Flexibility	Nuisance
Unloading time	1	1/3	1	1/9	1/3	1/7	1/5	1/7
Waiting time	3	1	5	1/7	2	1/3	1	1/5
Delivery time	1	1/5	1	1/9	1/5	1/7	1/5	1/7
Space	9	7	9	1	7	5	9	5
Costs	3	1	5	1/7	1	1/5	1/3	1/5
Number of EPTs	7	3	7	1/5	5	1	5	1
Flexibility	5	1	5	1/9	3	1/5	1	1/5
Nuisance	7	5	7	1/5	5	1	5	1

Table L.2: Pairwise comparison matrix: Interim manager

	Unloading time	Waiting time	Delivery time	Space	Costs	Number of EPTs	Flexibility	Nuisance
Unloading time	1	1	7	1	1/2	1	1	1
Waiting time	1	1	5	1/5	1/3	1/3	1	1/3
Delivery time	1/7	1/5	1	1/7	1/5	1/5	1/5	1/5
Space	1	5	7	1	1/5	1	1	1/3
Costs	2	3	5	5	1	5	5	1
Number of EPTs	1	3	5	1	1/5	1	2	1
Flexibility	1	1	5	1	1/5	1/2	1	1
Nuisance	1	3	5	3	1	1	1	1

Table L.3: Pairwise comparison matrix: Traffic manager

	Unloading time	Waiting time	Delivery time	Space	Costs	Number of EPTs	Flexibility	Nuisance
Unloading time	1	1/2	7	1/2	7	1	1/3	1
Waiting time	2	1	7	1/2	7	3	1/5	1
Delivery time	1/7	1/7	1	1/7	2	1	1/7	1/5
Space	2	2	7	1	9	7	1/2	7
Costs	1/7	1/7	1/2	1/9	1	1/7	1/9	1/7
Number of EPTs	1	1/3	1	1/7	7	1	1/7	1
Flexibility	3	5	7	2	9	7	1	7
Nuisance	1	1	5	1/7	7	1	1/7	1

L.2 Normalized Data: Flexibility and Costs

To be able to rank the designs the data has to be normalised. This normalisation is done based on simulation outputs and pairwise comparison. To determine the ranks the normalized data is multiplied with the criteria weights.

L.2.1 Costs and Flexibility

Flexibility and costs are two criteria that are hard to express in a numerical value. For flexibility this is the case since there is no numerical value for it. The costs for the different designs are hard to determine since there are a lot of insecurities. Therefore, the decision is made to determine the weights of these criteria based on a pairwise comparison. To be able to perform these pairwise comparison it has to be determined which designs are most flexible and costly.

The pairwise comparison of costs if found in Table L.4. The current design does not need any investments and is therefore the cheapest. Design 2 needs big tunnels and an underground logistic center therefore this design is expected to be the most expensive. Designs 1, 3, 4 and 5 use the same tunnels so the costs to construct the tunnels are similar. However, designs 3, 4 and 5 require extra investments. These costs are for example infrastructure adjustments for conveyors, AGVs and RGVs. Therefore, it is expected that the costs of these three designs are higher than for design 1.

Table L.4: Pairwise comparison matrix costs

	Current	Design 1	Design 2	Design 3	Design 4	Design 5	**Weight**
Current	1	3	9	5	7	3	**0,423**
Design 1	1/3	1	7	5	5	3	**0,273**
Design 2	1/9	1/7	1	1/3	1/3	1/5	**0,029**
Design 3	1/5	1/5	3	1	3	3	**0,123**
Design 4	1/7	1/5	3	1/3	1	1/3	**0,050**
Design 5	1/3	1/3	5	1/3	3	1	**0,102**

The flexibility of the designs is determined based on how well the designs can cope with goods delivered without a pallet and with disruptions. The current design is the most flexible followed by design 2 and 1. Design 1 and 2 are pretty flexible since goods are transported by humans and they can adjust the goods. In case of a disruption transportation can still continue since the vehicles can drive around each other within the tunnels. Design 3 is expected to be the least flexible. The reason for this is that it works with fixed conveyors through the tunnel. This means that the tunnels can only be used by conveyors and it is not possible to use an EPT for certain goods. When the conveyors have a malfunction the whole transportation stops. Design 4 and 5 are also expected to be less flexible due to the same reasons as design 3. However, for these designs there is the possibility to share the tunnel with AGVs, RGVs and EPTs. This way certain goods with odd measurements can still be transported by humans. The pairwise comparison matrix of flexibility is shown in Table L.5

Table L.5: Pairwise comparison matrix flexibility

	Current	Design 1	Design 2	Design 3	Design 4	Design 5	**Weight**
Current	1	3	3	7	5	5	**0,425**
Design 1	1/3	1	1	5	3	3	**0,191**
Design 2	1/3	1	1	5	3	3	**0,191**
Design 3	1/7	1/5	1/5	1	1/3	1/3	**0,037**
Design 4	1/5	1/3	1/3	3	1	1	**0,078**
Design 5	1/5	1/3	1/3	3	1	1	**0,078**

L.3 AHP Rankings

The designs are ranked from best to worst for different scenarios. A ranking of 1 means the best and a ranking of 6 the worst. In total 4 scenarios are included: 280 vehicles, 160 and 400 vehicles with an operational time of 12 hours and 400 vehicles with an operational time of 16 hours. The ranking can be found in the tables below.

Table L.6: Normalised data: 280 vehicles, operational time 12 hours

	Unloading times	Waiting times	Delivery times	Space	Number of EPTs & forklifts	Flexibility	Nuisance	Costs	Weighted score	**Rank**
Current	0.095	0.012	0.135	0.116	0.233	0.425	0.001	0.423	0.170	**3**
Design 1	0.181	0.177	0.148	0.175	0.121	0.191	0.200	0.273	0.181	**1**
Design 2	0.180	0.028	0.232	0.183	0.153	0.191	0.200	0.029	0.158	**5**
Design 3	0.181	0.216	0.059	0.161	0.176	0.037	0.200	0.123	0.152	**6**
Design 4	0.182	0.357	0.217	0.182	0.158	0.078	0.200	0.050	0.175	**2**
Design 5	0.181	0.210	0.209	0.183	0.158	0.078	0.200	0.102	0.164	**4**

Table L.7: Normalised data: 160 vehicles, operational time 12 hours

	Unloadig times	Waiting times	Delivery times	Space	Number of EPTs	Flexibility	Nuisance	Costs	Weighted score	**Rank**
Current	0.101	0.015	0.130	0.112	0.216	0.425	0.001	0.423	0.168	**3**
Design 1	0.180	0.197	0.181	0.178	0.127	0.191	0.200	0.273	0.186	**1**
Design 2	0.179	0.197	0.203	0.178	0.160	0.191	0.200	0.029	0.173	**2**
Design 3	0.178	0.197	0.120	0.176	0.169	0.037	0.200	0.123	0.155	**6**
Design 4	0.180	0.197	0.187	0.178	0.166	0.078	0.200	0.050	0.158	**5**
Design 5	0.181	0.197	0.180	0.178	0.163	0.078	0.200	0.102	0.161	**4**

Table L.8: Normalised data: 400 vehicles. operational time 12 hours

	Unloadig times	Waiting times	Delivery times	Space	Number of EPTs	Flexibility	Nuisance	Costs	Weighted score	**Rank**
Current	0.118	0.198	0.184	0.122	0.233	0.425	0.001	0.423	0.194	**1**
Design 1	0.174	0.189	0.069	0.158	0.121	0.191	0.200	0.273	0.175	**2**
Design 2	0.173	0.091	0.247	0.192	0.158	0.191	0.200	0.029	0.167	**3**
Design 3	0.181	0.199	0.050	0.144	0.176	0.037	0.200	0.123	0.145	**6**
Design 4	0.179	0.179	0.226	0.192	0.155	0.078	0.200	0.050	0.159	**5**
Design 5	0.176	0.144	0.223	0.192	0.158	0.078	0.200	0.102	0.160	**4**

Table L.9: Normalised data: 400 vehicles. operational time 16 hours

	Unloadig times	Waiting times	Delivery times	Space	Number of EPTs	Flexibility	Nuisance	Costs	Weighted score	**Rank**
Current	0.095	0.007	0.149	0.120	0.234	0.425	0.001	0.423	0.171	**2**
Design 1	0.181	0.230	0.080	0.165	0.122	0.191	0.200	0.273	0.182	**1**
Design 2	0.179	0.011	0.255	0.189	0.153	0.191	0.200	0.029	0.158	**5**
Design 3	0.181	0.251	0.049	0.149	0.177	0.037	0.200	0.123	0.152	**6**
Design 4	0.183	0.298	0.239	0.189	0.153	0.078	0.200	0.050	0.171	**3**
Design 5	0.180	0.203	0.227	0.189	0.161	0.078	0.200	0.102	0.166	**4**

M | Scientific Paper

Queuing Strategies to Regulate Inbound Logistics at Convention Centers a Case Study of the RAI Amsterdam

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Abstract

Convention centers are facing logistic challenges due to poor performance, lack of space and governmental regulations. This research is focused on finding strategies that can improve performance while maintaining or reducing space and complying to these governmental regulations. In this paper three main strategies are introduced that can improve logistic performance at convention centers. These main strategies are: a truck appointment system, extended operational times and cross-docking. Besides these strategies specific designs are made for the case of the RAI Amsterdam. These designs differ in infrastructure and material handling equipment such as automated vehicles. It was found that implementation of a truck appointment system, extended operational times and cross-docking can improve the performance of convention center logistics. Further improvements can be made by adjusting the infrastructure and by the use of automated vehicles.

Keywords: Queuing theory, Discrete event simulation, Logistics, Convention centers, Truck appointment system, Cross-docking

1. Introduction

The RAI Amsterdam is the largest convention center in the Netherlands. The main source of income for a convention center is selling commercial space. In order to host many conventions a good logistics system is necessary. Logistics at convention centers are highly complex due to the variety of goods, the small time-span and the different logistic activities [1]. For a convention build-up hundreds of trucks deliver materials, which all need to be handled by the convention center.

The logistic department of the RAI faces two main challenges:

- In order to increase its income, a convention center would like to increase the amount of commercial space. Since space is limited, space with other purposes such as logistic space is transformed into commercial space. Reducing logistic space decreases the capacity of unloading spots. A lower capacity can result in queues and extensive waiting times. Queues are undesirable since they take up space and decrease the performance of the logistics system [2]

- It is located in a highly urbanized part of Amsterdam. This location is desirable since it increases the attractiveness of the convention center and attracts more exhibitors and visitors [3]. However the urban location faces stricter government regulation aimed at reducing negative external effects. Examples of these regulations are: environmental zones and road pricing [4].

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1.1. Research Gap

Limited research has been done into the subject of convention center logistics. This research will try to find an answer to the question how convention center can improve their performance. Factors will be identified that influence the logistic performance at convention centers during the build-up phase of a convention. In order to improve performance several strategies can be used that will be included in a new design of convention center logistics. Besides improving performance it is important that these strategies and designs reduce negative external effects in order to comply with governmental regulations. They should also maintain the amount of commercial space since a decrease will lead to lower incomes. This research will answer the following research question:

How can the RAI redesign the freight logistics system to reduce negative external effects, improve logistic performance and maintain commercial space?

In order to answer this main research question six subquestions are used:

1. *Which logistic problems are convention centers facing?*
2. *Which technologies and strategies can be used to improve logistic performance at convention centers or similar industries?*
3. *How is freight currently transported to, from and within the RAI and why is it not optimal?*
4. *How does the current logistics system affect performance, nuisance and space?*
5. *Which logistics system designs can be implemented and how do they affect the performance, nuisance and space?*

6. *Which factors are decisive for the optimal logistics system of a convention center?*

In order to provide an answer to the corresponding research question, this paper will continue with a section that briefly describes the used methodologies. In the next section the proposed designs will be outlined. This is followed by an explanation of the simulation model and the scenarios that were used. Then the results of the research will be presented followed by a conclusion, discussion and recommendations for further research.

2. Methodology

2.1. DMADV

To structure the research the design method DMADV is used. This method is suitable to analyse and improve processes that have not been implemented yet [5]. The DMADV method consists of five phases. The first phase is the **Define** phase it contains the background and reasons for the project. Within the second phase, **Measure**, the current logistics system at the RAI is analysed and the required data is gathered. The gathered data is then analysed in the third phase, **Analyse**. In the fourth phase, **Design**, different logistic designs are introduced, which can be used to improve performance. Different scenarios are used to see the behaviour of the designs. Within the final phase, **Validate**, the outcomes of the proposed designs are evaluated with the use of the Analytical Hierarchy Process (AHP).

2.2. Literature

Since literature is lacking on how convention centers can reduce queues and increase system performance, literature on other industries was used. The goal was to find methods and technologies used within these industries that improve system performance and could be implemented within convention centers. These industries are: ports, mass-events, warehouses and distribution centers. These industries show similarities with convention centers since they handle incoming trucks and trailers and various types of goods.

Ports are dealing with port congestion, this occurs when trucks have to wait for their container at the port. These trucks waiting for their container can be seen as a queue. One strategy to decrease port congestion is increasing the capacity of the port. This can be done by increasing the number of gates, cranes and storage space. However, expanding is often costly and space is limited. Other strategies are controlling the arrival process of arriving trucks with the use of time windows, toll systems and a truck appointment system [6]. A truck appointment system is the most controlling system of the three. The port makes a set of time-slots and determines the maximum number of trucks per time-slot. Trucks are forced to pick an available time-slot before arrival and are only allowed to enter the port within this time-slot. This system ensures that the amount of arriving trucks do not exceed the capacity and all information about arriving trucks is known beforehand [7].

Warehouses and distribution centers have to handle incoming trucks and have to transport and store goods within the warehouse or distribution center. A strategy used to reduce inventory space is cross-docking. With cross-docking inbound trucks are linked to outbound trucks and the goods are immediately loaded onto the outbound truck. By doing this goods do not have to be stored, which reduces inventory space and costs [8]. Within warehouses automation and standardization is often used. This is often combined with implementation of automated vehicles. Several types of automated vehicles exists such as Automated Guided Vehicles (AGVs), Rail Guided Vehicles (RGVs) and autonomous vehicles. Implementing automated vehicles can improve system performance and decrease operation costs [9]. Apart from AGVs other systems are used automation such as conveyor belts.

Mass events hold large events similar to convention centers. However, the location used for mass events is often not designed with the event as its main purpose. The way the infrastructure and the logistic is set up has an impact on the logistic performance of the event [10]. The logistics at mass events is often outsourced to external companies, which take care of all the logistics. This is often more efficient since these companies have the right equipment and knowledge [11].

2.3. Queuing Theory

Queuing theory describes the process of queuing, why it occurs and how it evolves over time. The goal of queuing research is to determine the main performance of the system [2]. In a queuing system the served units are called entities. These entities arrive based on an arrival distribution. The arrived entity is served if the server is available. The serving time is also determined by serving distribution. If the server is not available the entity has to wait in the queue until it becomes available. Deciding which entity is picked from the queue is determined by the queuing discipline. Examples of queuing disciplines are first-in, first-out (FIFO), last-in, first-out (LIFO) and entity priority. In queuing theory three main model types are used. They can be deterministic, probabilistic or a mixed model. Within a deterministic model the arrival and service rates are known and within a probabilistic model they are unknown and distributions are used. The final option is a mixed model where one of the two rates is known and the other one is unknown. Besides the arrival and service rates, a queuing model consists of one or multiple servers. If a queuing model consists of multiple servers they are often used parallel and the services are identical. The most basic queuing system consists of a Poisson distributed arrival process, an exponential distributed service process and 1 server. The performance of these kind of queuing systems are easy to solve with the formulas of queuing theory. If more servers are included and if other distributions or real-world data is used it is difficult to solve these queuing problems with formulas [12]

To be able to determine the performance of a queuing system, several performance measures exists. These are: time in queue, time in system, number in queue, number in system and utilization of servers [12]. To increase performance and reduce queues much research has been done into this subject. Methods to reduce queues and waiting times are [13]:

- Reducing the amount of arrivals
- Reducing arrival peaks
- Increasing service efficiency
- Setting proper queuing disciplines

Queuing theory tries to capture the steady-state of a system, in other words, the long term behaviour. If the short-term behaviour is of interest, simulation can be used to capture this short-term behaviour. A simulation model is also capable of handling complicated queuing systems. Outcomes of simulation models are expected to have a higher chance of reflecting real-world behaviour[12].

2.4. Simulation

Different simulation techniques exist for example: system dynamics, Discrete Event Simulation (DES) and agent based simulation [14]. Deciding which simulation technique to use is dependent on the characteristics of the system that is studied. Important characteristics are whether the system is dynamic, deterministic or stochastic and if it is continuous or discrete [15]. System dynamics is often used for continuous systems and DES for discrete systems [16]

The logistics of a convention center can be described as a dynamic stochastic discrete system. Therefore, the best suited simulation method is discrete event simulation (DES) [16]. DES models are developed to mimic behaviour of a system and keeps track of the performance and the conditions the system is in. The performance and the conditions of a system at a given time is called a state. These states can only change instantaneously by the occurrence of an event [17]. The tool used to perform the DES is Simio.

3. Designs

3.1. Case Study: RAI Amsterdam

The RAI Amsterdam is located within Amsterdam, in Figure 1 the RAI and its surroundings is shown. The RAI is enclosed by a residential area on the north and east side, a recreational park on the left side and a highway and train track on the south side. The available logistic space is located around the halls on the north side and the south side. Since the RAI is enclosed by these areas expanding the terrain is impossible.

The RAI is facing strict governmental regulations. One of these regulations stipulates that freight traffic is no longer allowed on the north side of the RAI due to nuisance to the neighbourhood. This means that all logistics should be moved to the south side. The logistic space on the north side will no longer be available, which reduces the available logistic space with more than 50%. If the RAI still wants to be able to build-up and break-down conventions within the given time period the logistics system should undergo severe changes.

After studying the current logistic processes of the RAI, several possibilities for improvements emerged. Improvements could be made on: communication, peak-behaviour, inefficient

Figure 1: RAI surroundings

unloading and nuisance to the neighbourhood on the north side. Communication is lacking mainly between transporters to the RAI. There is no indication of the amount of trucks and trailers arriving per day and their loads, which makes the unloading process chaotic. Trucks and trailers can arrive whenever they want, resulting in peak-behaviour during popular hours. The unloading process of trucks and trailers is slow since they are unloaded one pallet at a time either by hand or by forklift. The pallet is brought to the hall, which takes several minutes, and is delivered. The forklift has to drive all the way back to the truck to pick-up the next pallet and repeats this process until the trucks is empty. Therefore, the unloading time often exceeds the maximum time limit, which is 45 minutes for a truck and 60 for a trailer. Trucks and trailers are unloaded one pallet at a time either by hand or by forklift. Long unloading times lead to a longer occupation of the unloading spot, which reduces the capacity. In the current situation more than half of the arriving trucks and trailers unload on the north side of the RAI, which leads to nuisance to the neighbourhood.

3.2. Proposed Designs

Based on the literature study several designs are made. These designs consists of a number of strategies that are applicable to all convention centers and a number of specific strategies that are only applicable to the RAI. If these general strategies improve performance the decision is made to implement them within all designs.

There are three general strategies which are: a truck appointment system, extending operational times and cross-docking. A truck appointment system is used to gather information of transporters before they arrive. It can also decrease peak-behaviour since there is a maximum number of trucks and trailers per time-slot. Extending operational times is used in combination with the truck appointment system. If there are more time-slots per day the amount of trucks and trailers in every time-slot can be further reduced. Cross-docking is used to speed up the unloading process. As soon as a truck or trailer arrives there are designated forklifts that unload the truck or trailer. Instead of bringing the pallets to the hall they drop the pallets at a buffer area near the unloading spots. At the buffer area the pallets are picked up by other vehicles such as Electric Pallet Trucks (EPTs), which deliver the pallets to the final destination within the hall.

These main strategies try to decrease unloading times and waiting times; however, the RAI is facing another problem: the closure of the north side. The main strategies are not able to solve these problems. Therefore, the logistic space has to be relocated or changed. To decide on the lay-out of the designs a requirement analysis is performed. The requirements are obtained by interviews with several stakeholder within the RAI Amsterdam. Five different infrastructural designs are introduced:

1. Design 1: Everything on south side
2. Design 2: Underground logistics on north side
3. Design 3: Conveyor belt through tunnel
4. Design 4: Rail guided vehicles trough tunnel
5. Design 5: Automated guided vehicles through tunnel

All designs incorporate an underground tunnel from the south side to the north side. In Figure 2 an example of the tunnel layout for designs 1, 3, 4 and 5 is shown. Figure 3 shows an example of the tunnel for design 2. Within these designs the north side of the RAI is closed-off completely. Trucks and trailers delivering to the north side have to unload at the south side (designs 1, 3, 4 and 5) or unload underneath an exhibition hall (design 5). In all the designs the same capacity of unloading spots is expected based on information from the RAI and an architect. The capacity can be seen in Table 1.

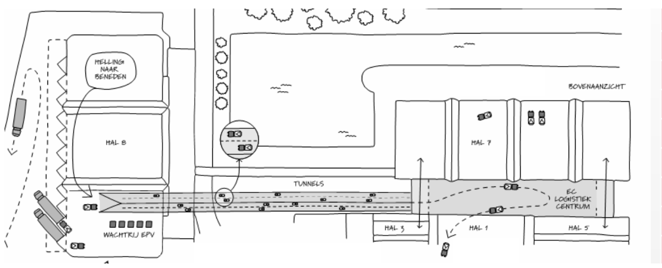

Figure 2: Example tunnel design 1, 3, 4 & 5

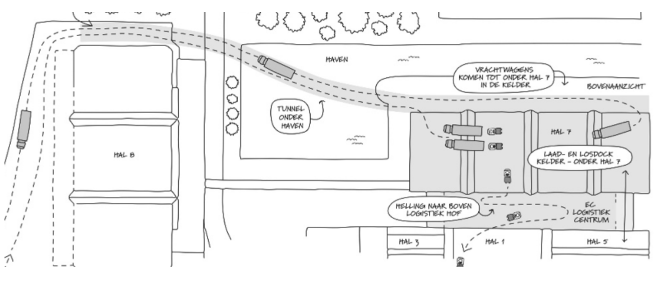

Figure 3: Example tunnel design 2

3.3. System Performance

To determine the performance of the system key performance indicators (KPIs) are introduced. The following KPIs are used:

- Space: logistic space required at RAI site
- Unloading time: time required to unload truck or trailer
- Waiting time: time a truck or trailer has to wait on an unloading spot
- Delivery time: time it takes to deliver goods to the final location within the hall
- Number of vehicles: total number of forklifts and EPTs used on the RAI site
- Nuisance: total number of trucks and trailers that enter the RAI via the north side
- Costs: estimated investment costs

4. Simulation

4.1. Simulation Model

As mentioned before the RAI Amsterdam is considered within this research. A DES model of the RAI is made with the simulation program Simio. The infrastructure of the RAI is modelled to scale within the simulation program. The inputs of the model consists of the arrival tables of trucks and trailers, which consist of the arrival time and the arrival destination. These tables are based on real arrival data collected by the RAI. In the model it is possible to control certain aspects such as: fleet sizes of EPTs and forklifts, speed of EPTs and forklifts, infrastructural set-up and arrival with or without a truck appointment system. The model records the unloading times for every truck and trailer, the pallet delivery time, waiting times of trucks and trailers and the number of trucks and trailers unloading at the north side.

A simulation model is made of the current situation in order to verify and validate the simulation model. In order to simulate the designs the simulation model of the current situation will be adjusted to the new designs. To verify and validate the current simulation model several methods are used. First, it is checked if the simulation model passes several general checks such as: forklifts can only pick-up one pallet at the time and all trucks and trailers leave after unloading. Second, different scenarios are run to see if the behaviour of the simulation models is as expected. Finally, the outcomes of the simulation model are compared to the real-world data. After doing visual checks and studying the model outputs it can be said that it passed all general checks and showed the expected behaviour.

The simulation model of the current situation is used to determine the effects of the main strategies. Based on the outcomes the decision is made whether to include these main strategies in the designs or not. The designs are simulated by adjusting the current simulation model.

4.2. Model Assumptions

In order to model the current situations several assumptions have been made. Assumptions are necessary since it is not possible to capture all real-world details in a simulation model. The most important assumptions will be discussed shortly. In the simulation model only two types of vehicles are included these are: trucks < 12 meters and trailers > 12 meters. Trucks and trailers arrive according to the arrival data without any randomness. A truck or trailer can either be a self-loader or uses the logistic partner for unloading. The logistic partner is allowed to use forklifts for the unloading of goods. A self-loader is not allowed to use any motorized equipment and transports the goods by hand. The assumption is made that all goods arrive on pallets and a forklift or self-loader can only transport one pallet at a time. The number of used forklifts is set on 40 and is based on given information from the logistic partner. More assumptions and inputs of the current simulation model can be found in Table 1 and Table 2.

The simulation models of the designs have many similarities to the simulation model of the current situation. However, there are some major differences. In Table 1 and Table 3 the assumed inputs for the simulation model of the different designs can be seen. The inputs of the number of EPTs, Forklifts, RGVs and AGVs are fixed and based on simulation outcomes. The designs have been run with different set-ups where the numbers of these vehicles are varied. The number is chosen where the unloading times or buffer sizes were reasonable and adding extra vehicles would not improve the outcomes significantly.

Table 1: Input parameters current & designs

Input parameter	Current		Designs	
	Truck	Trailer	Truck	Trailer
Unloading spots	58	46	46	24
Load (pallets)	5 =30% 10= 60% 15 = 10% 20 = 0%	5 = 10% 10 = 30% 15 = 30% 20 = 30%	5 =30% 10= 60% 15 = 10% 20 = 0%	5 = 10% 10 = 30% 15 = 30% 20 = 30%
Share self-loaders	70 %	20 %	0 %	0 %

Table 2: Input parameters current situation

Input Parameter	Value
Forklift speed oustide hall	5 km/h
Forklift speed near truck/trailer	2.5 km/h
Forklift speed within hall	Random.Uniform(1.5,4.2) km/h
Number of forklifts	40
Time before start unloading	Random.Uniform(1,15) minutes
Time to unload pallet from truck on forklift	Random.Uniform(30,240) seconds
Time to unload pallet from forklift on floor	Random.Uniform(30,60) seconds
Unloading and delivery time pallet self-loader	Random.Uniform(1.5,12) minutes
Registration time at RAI entrance	Random.Uniform(0.5,2) minutes
Truck/trailer speed on work site	5 km/h

Table 3: Input parameters designs

Input parameter	Value
Number of forklifts / EPTs	27/71
EPT pallet load time	Random.Uniform(30,60) seconds
EPT pallet unload time	Random.Uniform(30,60) seconds
EPT speed in tunnel	9 km/h
Design 3	
Conveyor belt speed	2 km/h
Time to load/unload pallet on conveyor	Random.Uniform(20,30) seconds
Design 4	
Number of RGVs	20
Loading/unloading time pallet on RGV	Random.Uniform(10,30) seconds
RGV speed	10 km/h
Unloading time forklift at RGV loading station	Random.Uniform(20,30) seconds
Design 5	
Number of AGVs	25
Loading/unloading time AGV	Random.Uniform(30,60) seconds
AGV speed	7 km/h
Unloading time forklift at AGV loading station	Random.Uniform(30,60) seconds

4.3. Experimental Plan

In the current simulation model the main strategies: a truck appointment system, extending operational times and cross-docking will be implemented. To research the effects of these strategies different scenarios are run. These scenarios differ in the amount of arriving vehicles, set-ups for the truck appointment system, various operational times and if cross-docking is used or not. The amount of arriving vehicles can be 160, 280 or 400 vehicles, which represent a normal, busy and very busy day. The arrival data of the 280 trucks and trailers is based on real-world data. The other two data sets are generated based on the probabilities of the existing data.

The truck appointment system can either have time-slot of an hour or 15 minutes. The amount of time-slots is influenced by the operational time. If operational time is extended the number of time-slots will increase. Operational times can be 12, 14 or 16 hours. Every possible combination is run, which results in the 18 scenarios. The input values of the model can be seen in Table 1 and Table 2. Cross-docking is either implemented or not. Every combination is run, which results in 36 scenarios, every scenario is run 25 times.

After simulating the current simulation and the main strategies the proposed designs are simulated. To see how the designs influence the performance several scenarios are introduced. These scenarios differ on the amount of arriving trucks and trailers (160, 280 and 400) and operational time (12, 14 and 16). Every combination is run, which results in 9 scenarios per design and every scenario is run 25 times.

5. Results

5.1. Truck Appointment System

In Table 4 the effects of implementing a truck appointment system on the unloading times and the waiting times is shown. It shows that extending operational times decreases the unloading times of logistic partner users and decreases overall waiting times. Only the unloading times of logistic partner users are affected. The reasons for this are that a more spread out arrival pattern ensures less pressure on the amount of forklifts. If all trucks and trailers arrive at the same moment the forklifts are busier and it takes more time to unload a truck or trailer. If scenarios are run with more arriving trucks and trailers the differences are even more clear, waiting times decrease from 83 minutes to 3 minutes. Using smaller time-slots, 15 minutes instead of one hour, decreases unloading times and waiting times slightly further.

5.2. Cross-docking

In Table 5 the effects of cross-docking can be seen. These outcomes are based on the arrival of 280 trucks and trailers. It shows that the unloading times of the logistic partner trucks and trailers decrease if enough forklifts are used. With the use of 40 forklifts the unloading times almost decrease with 50%. The amount of forklifts influences the unloading time. The amount of pallets within the buffer is influenced by the amount of forklifts and EPTs. If many forklifts are used, pallets are transported

Table 4: Influence peak-shaving on unloading and waiting times

Operational time/ time-slot	Unloading time (min) Trailer SL	Trailer LP	Truck SL	Truck LP	Waiting time (min)
280 Trucks & Trailers					
Base	98	92	64	66	16.9
12 hours, 1 hour	101	61	64	44	0.2
12 hours, 15 minutes	100	61	65	45	0.3
16 hours, 1 hour	102	56	64	40	0.2
16 hours, 15 minutes	98	54	64	39	0.2
400 Trucks & Trailers					
Base	98	92	65	53	82.6
12 hours, 1 hour	101	95	65	68	33.1
12 hours, 15 minutes	101	89	65	61	32.4
16 hours, 1 hour	97	72	64	48	5.7
16 hours, 15 minutes	98	69	64	45	2.8

quickly form the trucks and trailers into the buffer. If the EPTs can not keep up with this inflow the amount of pallets within the buffer increases.

If cross-docking is combined with peak-shaving further improvements can be seen. Unloading times decrease to 45 minutes for a trailer and 30 minutes for a truck. Waiting times decrease to 0 and the required buffer area reduces. Therefore, the decision is made to include both cross-docking and peak-shaving within the proposed designs.

Table 5: Influence cross-docking

Scenario Forklift/EPTs	Unloading time (min) Trailer SL	Trailer LP	Truck SL	Truck LP	Waiting time	Pallets in buffer
Base 40 FL, 0 EPT	98	92	64	66	16.9	0
40 FL, 20 EPT	99	51	65	33	2.5	848
20 FL, 20 EPT	99	93	64	90	6.0	543
40 FL, 40 EPT	101	50	65	33	2.4	357
20 FL, 40 EPT	100	91	65	88	5.5	34
Combination of cross-docking and peak-shaving						
40 FL, 20 EPT	99	45	64	31	0	348
20 FL, 20 EPT	101	53	64	40	0	255
40 FL, 40 EPT	97	45	64	29	0	131
20 FL, 40 EPT	98	52	64	39	0	31

5.3. Design Outcomes

The outcomes for every design can be seen in Table 6. The decision is made to only show the outcomes of these three scenarios since they show the distinctions between the designs. The unloading times are not included since they are similar in all designs. This is the case since the same unloading method is used in every design. The required buffer area can be reduced by implementing automated vehicles or locating the buffer near the destinations. In design 2 the buffer is located in close proximity to the halls, which leads to a smaller buffer area. Designs 4 and 5 use automated vehicles and need small buffers compared to designs 1 and 3. Delivery times are the longest in design 3 and the shortest in design 2.

5.4. Evaluation

Finally, the outcomes of the design simulation runs are normalised and an AHP is performed. The outcomes of the AHP for the scenario with 280 arriving trucks and trailers and an operational time of 12 hours can be seen in Table 7 Important criteria for the RAI are space, nuisance, flexibility, number of EPTs and waiting times. The least important criteria are unloading time, delivery time and costs. Based on the weights of

Table 6: Design outcomes

Design	Waiting time (min)	Delivery time (min)	Pallets in buffer	Used EPTs	Other Vehicles
280 vehicles, operational time 12 hours					
Design 1	1.1	47.0	228	50	0
Design 2	7.3	29.9	54	34	0
Design 3	0.9	117.8	562	20	6
Design 4	0.6	32.1	61	32	18
Design 5	1.0	33.2	48	32	27
400 vehicles, operational time 12 hours					
Design 1	83.4	135.4	876	50	0
Design 2	172.9	37.9	51	32	0
Design 3	79.1	185.6	1302	20	6
Design 4	88.3	41.4	54	33	19
Design 5	109.9	42.0	44	32	28
400 vehicles, operational time 16 hours					
Design 1	2.4	94.3	597	50	0
Design 2	48.5	29.7	46	34	0
Design 3	2.2	155.9	1052	20	6
Design 4	1.8	31.6	37	34	18
Design 5	2.7	33.3	29	31	27

these criteria, in the situation with 280 arriving trucks and trailers, design 1 scores best followed by design 4 and the current situation.

Table 7: Analytical Hierarchy Process outcomes, 280 arriving truck & trailers

Criteria	Weight	Current	Design 1	Design 2	Design 3	Design 4	Design 5
Unloading time	0.076	0.095	0.181	0.180	0.181	0.182	0.181
Waiting time	0.100	0.012	0.177	0.028	0.216	0.357	0.210
Delivery time	0.028	0.135	0.148	0.232	0.059	0.217	0.209
Space	0.280	0.116	0.175	0.183	0.161	0.182	0.183
Number of EPTs	0.129	0.233	0.121	0.153	0.176	0.158	0.158
Flexibility	0.153	0.425	0.191	0.191	0.037	0.078	0.078
Nuisance	0.162	0.001	0.200	0.200	0.200	0.200	0.200
Costs	0.072	0.423	0.273	0.029	0.123	0.050	0.102
Weighted score		0.170	0.181	0.158	0.152	0.175	0.164
Rank		**3**	**1**	**5**	**6**	**2**	**4**

Since the outcomes can differ per scenario an overview of the design scores for 4 scenarios can be seen in Figure 4. Design 1 scores best in 3 scenarios, only in the scenario with 400 trucks and trailers and an operational time of 12 hours the current design scores better. Design 3 has the lowest scores in every scenario.

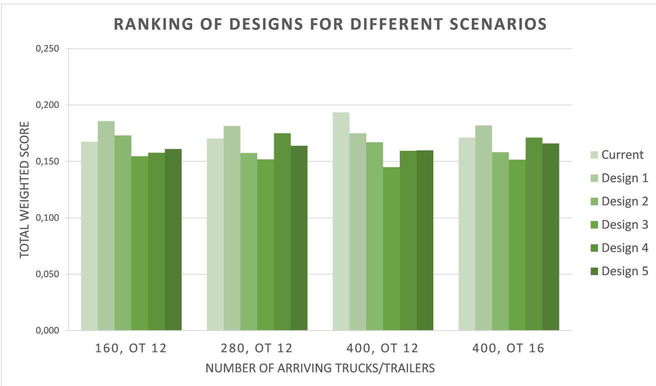

Figure 4: Design rankings for different scenarios

6. Conclusion

Considering the results of this research, several conclusions can be drawn on how convention centers can improve their performance. In general convention centers can improve their unloading times and waiting times with the implementation of a truck appointment system, extending operational times and cross-docking. With the implementation of these strategies the chances of exceeding the capacity due to peak-behaviour reduces. Cross-docking improves unloading times of trucks and trailers. A side-effect of cross-docking is that it requires a buffer area. The required buffer area depends on the inflow and outflow of the buffer. If the inflow is higher than the outflow the required space for the buffer area will increase. A higher outflow can be established with the implementation of automated vehicles or using more manual EPTs. The influence of cross-docking is only applicable to trucks and trailers that unload with the use of the logistic partner. Therefore, the convention center can decide to only allow unloading by logistic partners. On calm days there were only small improvements in unloading and waiting times. However, during busy days large improvements were seen. Implementing these strategies speed up the processes and controls the arrival behaviour. Due to this fact less capacity is needed since high peaks are eliminated. This means that on a daily basis the same amount of trucks and trailers can be handled with less unloading spots. Logistic space could be reduced to increase commercial space.

The implementation of cross-docking, extended operational times and a truck appointment system have challenges. Since the unloading times only decrease for logistic partner users a decision can be made to prohibit self-unloading. However, if all trucks and trailers unload with a logistic partner more forklifts and EPTs are necessary, which increases the costs. These costs need to be paid by either the customers or the convention center. The implementation of a truck appointment system will only allow a certain amount of trucks and trailers during a time-slot. If the desired time-slot is full transporters have to pick another time-slot. This could result in a delivery that is too late, which could result in a delay during the build-up. When operational times are extended transporters and builders have to be willing to work later. If they refuse to work later extending operational times is not an option.

For the case of the RAI several designs were proposed that included cross-docking and a truck appointment system. Simulating these designs and applying an analytical hierarchy process showed that there are only small differences between these designs. The results showed that overall design 1 is most promising since it is very flexible and scores well on waiting times and costs. However, as mentioned in section 8 the required buffer area is underestimated, and design 1 needs a large buffer area compared to other designs. All designs reduce the nuisance compared to the current design, Design 2 is very costly and has long waiting times and is therefore excluded as a desirable option. Design 3 performs overall the worst and is therefore also excluded as a desirable option. Designs 4 and 5 score similar and perform well. However, they are less flexible than design 1 and 2. Design 1, 4 and 5 are considered to be good options for the RAI and the differences between them are small. If the RAI decides to go with option 4 or 5, which uses automated vehicles they are the first convention center to include these vehicles. In the designs these vehicles are only used within the tunnel. However, if the RAI can improve the infrastructural situation in the halls implementation of automated vehicles could be possible. This could improve efficiency even further and decrease operational costs.

These designs show that they influence the performance of a convention center in different ways. Depending on the characteristics and requirements of a specific convention centers designs should be made. The designs will differ for every convention center. However, a good design can improve performance, reduce required space and make sure that the logistics comply with governmental regulations.

7. Discussion

This research contributed to the literature on convention center logistics. Limited research has been done into convention center logistics and how convention centers can improve this performance. This research gives insights in how convention centers can regulate inbound traffic to reduce queues and excessive waiting times. It also shows how convention centers can handle the pressure of municipalities to reduce nuisance.

However, this research has its limitations as well. Space is an important criterion for the RAI and consists of the buffer area and the space required for the unloading spots. The required buffer area is only a small part of the total space since the space required for unloading spots is large. Within the AHP the total space is used and therefore, the required space for the buffers is underestimated. The simulation model contains many assumptions since real-world data is lacking. Assumptions have been made based on the knowledge of experts at the RAI. Besides using assumptions many details are left out within the model since this would highly increase the complexity of it. This research focuses mainly on the build-up phase of a convention. However, a convention always has a build-up and a break-down phase and these phases differ considerably. This research is performed with the RAI Amsterdam as a case study. The simulation model is based on the RAI site which means that outcomes and conclusions are based on this specific site.

8. Recommendations for Further Research

Further research should be done into the break-down process of conventions. The break-down process of a convention differs a lot from the build-up processes. Research should focus on how a truck appointment systems and cross-docking could be implemented at the break-down process as well. In this research the infrastructure and situations within the halls are not included. However, this could have a major influence on the logistics. Normally, the infrastructure and the situation within the halls differ every day. A better infrastructure within the halls could improve moving speeds of forklifts and EPTs, which could decrease unloading times and delivery times. Furthermore, research should be done into how the new designs affect the egress and access roads.

Besides further research on system performance this research showed that implementing new strategies highly affects employees and stakeholders at the RAI. Implementing and operating these strategies is expensive. Research should be done into how these costs can be covered and what effect this has on the stakeholders and the competitive position of the convention center.

References

[1] S. X. Zhang, Research on exhibition logistics information platform construction, Applied Mechanics and Materials 241-244 (2012) 3205–3208. doi:10.4028/www.scientific.net/AMM.241-244.3205.

[2] J. Sztrik, Basis Queueing Theory: Foundations of System Performance Modeling, GlobeEdit, 2016.

[3] ExhibitCity, Convention centers face fierce competition — exhibit city news, 2014. URL: https://exhibitcitynews.com/convention-centers-face-fierce-competition/.

[4] H. Quak, L. Tavasszy, Customized solutions for sustainable city logistics: The viability of urban freight consolidation centres, in: J. A. E. E. van Nunen, P. Huijbregts, P. Rietveld (Eds.), Transitions towards sustainable mobility, volume 43, Springer, Berlin and New York, 2011, pp. 213–233. doi:10.1007/978-3-642-21192-8{\textunderscore}12.

[5] K. Jenab, C. Wu, S. Moslehpour, Design for six sigma: A review, Management Science Letters (2018) 1–18. doi:10.5267/j.msl.2017.11.001.

[6] H. Zhang, Q. Zhang, W. Chen, Bi-level programming model of truck congestion pricing at container terminals, Journal of Ambient Intelligence and Humanized Computing 10 (2019) 385–394. doi:10.1007/s12652-017-0641-y.

[7] C. Caballini, J. Mar-Ortiz, M. D. Gracia, S. Sacone, Optimal truck scheduling in a container terminal by using a truck appointment system, in: 2018 21st International Conference on Intelligent Transportation Systems (ITSC), IEEE, 2018, pp. 2525–2530. doi:10.1109/ITSC.2018.8569623.

[8] W. Yu, P. J. Egbelu, Scheduling of inbound and outbound trucks in cross docking systems with temporary storage, European Journal of Operational Research 184 (2008) 377–396. doi:10.1016/j.ejor.2006.10.047.

[9] P. Ribino, M. Cossentino, C. Lodato, S. Lopes, Agent-based simulation study for improving logistic warehouse performance, Journal of Simulation 12 (2018) 23–41. doi:10.1057/s41273-017-0055-z.

[10] M. Dziadkiewicz, M. Kadlubek, S. Legowik-swiacik, N. Baskiewicz, The importance of logistics infrastructure in mass event management, Valahian Journal of Economic Studies 7 (2016) 37–44.

[11] A. Creazza, C. Colicchia, F. Dallari, Designing the venue logistics management operations for a world exposition, Production Planning & Control 26 (2015) 543–563. doi:10.1080/09537287.2014.929190.

[12] W. D. Kelton, J. Smith, D. T. Sturrock, Simio and simulation: Modeling, analysis, applications, 3. ed., rev ed., Simio, Sewickley, Pa., 2014.

[13] L. Y. Wang, Y. Feng, A study to setting function of queuing discipline in highway tollgate, Advanced Materials Research 734-737 (2013) 1594–1597. doi:10.4028/www.scientific.net/AMR.734-737.1594.

[14] S. Abar, G. K. Theodoropoulos, P. Lemarinier, G. M. O'Hare, Agent based modelling and simulation tools: A review of the state-of-art software, Computer Science Review 24 (2017) 13–33. doi:10.1016/j.cosrev.2017.03.001.

[15] A. M. Law, W. D. Kelton, Simulation modeling and analysis, McGraw-Hill series in industrial engineering and management science, 2nd ed. ed., McGraw-Hill, New York and London, 1991.

[16] O. Özgün, Y. Barlas (Eds.), Discrete vs. Continuous Simulation: When Does It Matter?, 2009.

[17] M. Jacob, Discrete event simulation, Resonance 18 (2013) 78–86. doi:10.1007/s12045-013-0010-x.