Exploring the viability of AGV implementation in warehouses of express delivery companies.

A case study at TNT/FedEx

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PREFACE

This research is performed to fulfill the requirements of the Master of Science in Management of Technology at Delft University of Technology. During the research I have gained extensive knowledge about the viability of automated guided vehicles (AGV) within express delivery companies to close the knowledge gap in literature and companies. I have had great support from my girlfriend, friends and family during my research and I would like to express my gratitude to my supervisors from the university V. Dignum and JA. Annema. They were always willing to listen to my thoughts, were open to brainstorm about the research during the meetings, provided good feedback and were flexible in planning meetings. Additionally, I would like to thank JA. Annema for the extra support in the final phase of the research. Finally, I would also like to thank the company supervisor C. Turta and E. van der Lande for their support during the research. Many brainstorm sessions have helped to understand the current processes and the potential of AGVs.

I hope you enjoy reading my thesis.

Santino van Walsum

Hoofddorp, July 20, 2018

ABSTRACT

The demand for express delivery services is growing rapidly and the express delivery market is getting more competitive. To secure their competitiveness, these enterprises are pressured to invest in technologies that could sustain their future growth and keep their operating costs as low as possible. The Automated guided vehicle (AGV) technology could increase the competitiveness of these enterprises by reducing both operating costs and labour demand. Until now insufficient knowledge is available within express delivery companies regarding the viability of AGVs. The main objective of this research is to determine whether AGVs are viable for use within the warehouses of express delivery companies. Initial research found that the non-conveyor (pallet) process was most interesting to investigate because this process is currently expensive, labour intensive and many accidents happen in this process. The non-conveyor process is the process where pallets are handled and is divided in three parts: the loading, unloading and transporting area. The early phase of the research found that loading and unloading of trucks could not be automated by AGVs due to the time pressure and the technical challenges like the large variety of pallet types. This made the research focus on the transporting part of the pallets in the warehouse.

Literature is reviewed to identify a method on how viability of AGVs could be determined. Research has shown that there is not yet a standard assessment method and the most common used methods were only including financial measures which is to specific for the management of technology environment. In this research innovation theory is used to identify important viability factors which could determine the overall viability. This theory was chosen and expected to be suitable because it describes the factors that were barriers for large scale implementation of technologies which are also factors that make the technology unviable for implementation for companies and is not only focussed on the financial aspect. The identified relevant factors to determine the viability were the technical, financial, regulatory and social factors. These factors were evaluated for three different warehouses within TNT in the form of a case study. A multiple case study is chosen because case studies can obtain in depth knowledge about specific cases and multiple cases increase the reliability and generalizability of results. The case study at the three warehouses has shown that the conveyor AGV could be viable in new or expanded warehouses if conveyor tables would be implemented. The conveyor AGV type is recommended because it is more viable then the forklift AGV type. The conveyor AGVs can handle more pallet types and has higher performance. The building has to be expanded or a new one must be used due to the fact that in the current warehouses are too small for AGV operations, because AGVs are slower and there is not enough space to operate with both manual forklifts and AGVs. The conveyor tables are required to separate the loading and unloading place from the AGV pick up place to increase the efficiency of the loaders and unloaders. Furthermore, it is recommended to implement AGVs in new warehouses to reduce the resistance of the social environment. In every implementation case a social plan has to be written and approved which explains what will happen with the employees after implementing such a technology. This is not the case when a new warehouse will be opened. The financial measures are important for companies to decide whether a technology is useful. Therefore, the financial results are evaluated on the reliability and robustness by performing a sensitivity analysis. This analysis has shown that the financial viability will still be positive in different scenarios and it also identified the impacting factors. Impacting factors are defined as the variables that have the highest impact on the financial results. These impacting variables could be used to make an estimation on whether the AGVs will be viable in a specific warehouse. It is recommended to perform a viability study for every implementation project because it is interesting to obtain the case specific financial outcomes. The established calculation model could be used for this.

Standardized and continuous processes are believed to be most viable for AGV operations. This research found that an AGV implementation can also be financial attractive in processes where only a part of the flow can be automated and where the process is not running 24 hours a day. Furthermore, the identified technical limitations are the ones which are also expected to be most common in other industries and could be used to identify the viability in other industries. Moreover, the financial viability is calculated in the transport process which could apply to multiple industries where pallets will be transported from a to b. Another finding was that the buffer to buffer process takes place in the relative large warehouses.

Research has shown that results of a case study are not necessarily generalizable which implies that the results do not prerequisite apply for every express delivery company. TNT is expected to have similar processes as other express delivery companies. Difference in packages types could exist, but is not expected to be less standardized then TNT which will only have a positive effect on the results for express delivery companies. Increased standardization will only lead to higher financial benefits because the process still will be executed in the same way. Moreover, the location of the warehouses could change the financial results due to the fact that the impacting factors are different. The social and regulatory viability will not differ between the different companies but between different countries and have to be determined per country where AGVs will be implemented. The three analysed warehouses are financially attractive while these different warehouses have different input variables. This suggest that this will also apply for other warehouses. Until now there is not yet a layout design for the use of AGVs different from the current situation and this must be researched. Another important aspect is obtaining a proof of concept of the AGVs in the warehouses to verify the assumptions made in this research. If this is done successfully, warehouses could be chosen based on the impacting factors to automate a warehouse which is most viable. Also, the technical, regulatory, social environmental factors and additional benefits have to be incorporated. The academic recommendations are more focussed on obtaining generalizable results, because this is desired in the academic environment. As mentioned earlier the warehouses results are depending on different input variables which are depended on the different countries. To obtain more generalizable results more research should be performed on the differing variable between the different warehouses and in different countries as well as how the layout could be optimized and how additional benefits could be quantified as mentioned in the discussion.

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1 INTRODUCTION

This is a revised report where the confidential information is deleted. Therefore, input variables as volumes, labour costs and forklift driver performance are changed by ratio. This makes the difference between the warehouses still representative but the input values with the financial results aren't.

1.1 CONTEXT

Several technology trends in the logistics industry will influence our future in a positive way. One of these major trends is advanced robotics. These robots have different kind of applications, such as self-driven cars, surgery robots and even robots that dismantle bombs. Many other robotic applications such as automated lawnmowers and vacuum cleaners are already used in our daily lives. Multiple factories have already implemented robots to assemble products with higher quality and lower costs compared to the initial work method. These robots are already improving our lives by eliminating tedious, dangerous, repetitive and boring tasks. Additionally, robots have more accuracy, precision and strength. Robotic technologies are not yet implemented on a large scale within express delivery companies while this could increase customer service, productivity, precision, and achieve lower operating costs (DHL Trend Research, 2016). The automotive industry has already implemented robots and realized a productivity increase of 100 percent and an accident decrease of 80 percent between 1975 and 1990 (Roland Berger, 2016).

Robotic solutions have developed very fast after large internet companies made robotics part of their expansion plans. These robotic technologies now start to mature and the production costs are declining significantly. This results in a turning point for the large scale diffusion of robotics within warehouses (Roland Berger, 2016). Researcher Zakomirnyi said: "The mass arrival of robots in logistics is no longer a question. The real question is how soon, and how to better prepare for it" (Zakomirnyi, 2016). The growing internet companies and the statement of Zakominiyi make it very important for society as well as for companies to increase their knowledge base of these technologies. Society needs to know what will happen with jobs in the future and for companies it is important to stay ahead of the competition.

One of the promising robotic technologies within transport companies and express delivery companies is the Automated Guided Vehicle (AGV). AGVs are vehicles that operate unmanned and move by an automatic control system. They could lead to a more sustainable and efficient process, which is necessary in a highly competitive market. The most prominent advantages of the AGVs are reduced labour and operating costs, increased productivity and reliability, and AGVs can work continuously without breaks or days off (Karabegović, 2015).

1.2 RESEARCH PROBLEM

Express delivery companies are characterized by the limited time to deliver packages (Zhu, 2010). Express delivery companies are pressured to be competitive by reducing costs, improving safety and increasing efficiency (Angappa Gunasekaran, 2016). Research has shown that around 85% of the express delivery companies want to increase automation and adopt new technologies (Honeywell, 2014). Currently, only five percent of the warehouses are fully automated (DHL Trend Research, 2016).

Honeywell performed research to the current challenges in distribution centers (warehouses) in different countries. One of the statements made by Honeywell was: "Distribution center managers are faced with significant cost saving challenges, which means they can't afford to let such levels of time wastage continue. Businesses should be looking at every workflow in detail, on a regular basis, to claim back the minutes and seconds they need to achieve these savings. As this research shows, reviewing their technology infrastructure may be the perfect place to start" (Honeywell, 2014). Moreover, Honeywell illustrated that labour cost reduction in distribution centers is the most desired element to reduce. This is shown in figure 1.

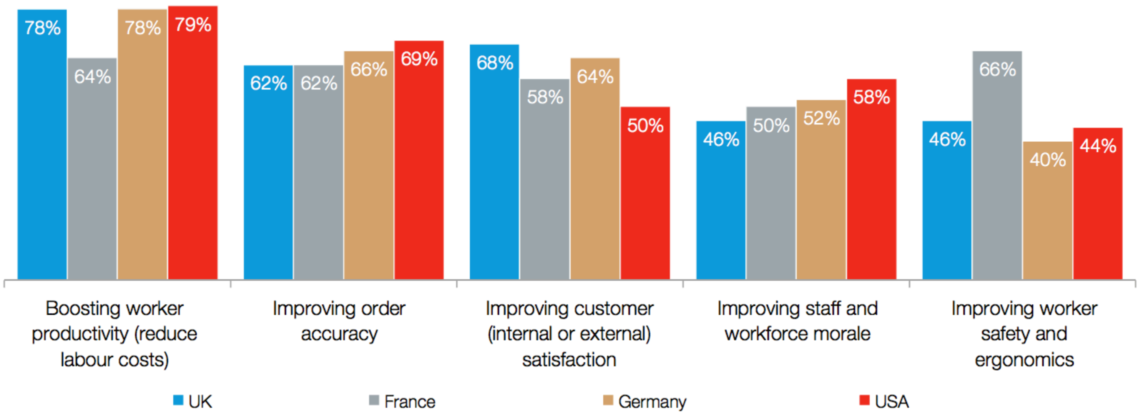

Figure 1 Improvement desires (Honeywell, 2014)

Furthermore, the continuously growing transport industry has lead to a shortage of employee supply. The warehouse in Arnhem, which is one of the research objects in this study, currently already has a shortage of ten to fifteen forklift drivers (Appendix XXVII). In conclusion, express delivery companies have to implement new technologies to reduce costs, improve the efficiency and to sustain their future growth. AGVs could potentially reduce operating costs, improve safety, improve efficiency and reduce labour demand in the warehouse of express delivery companies. This implies that the AGV technology could improve the safety, reduce costs and sustain the future growth because they are not dependent on the labour force. However, insufficient knowledge is available regarding the viability of AGVs within warehouses of express delivery companies, as well as in literature. The reviewed databases were googlescholar.com and sciencedirect.com. Examples of the searched keywords were the following: Performance of AGVs, Warehouses and AGVs, Distribution technologies, suitability of AGVS, Limitations of AGVS, Viability of AGVs, Business case of AGVs in delivery companies, transport companies, courier companies and many more. The mentioned problems led to the following research problem:

There is constant pressure to reduce costs and increase both safety and efficiency of the processes in the warehouses of express delivery companies. Until now there is insufficient knowledge available concerning the viability of Automated Guided Vehicles within the warehouses of express delivery companies.

1.3 Research objective and research questions

The main objective of this research is to obtain more knowledge about the viability of AGVs in the warehouses of express delivery companies to fill the knowledge gap in express delivery companies and literature. The following main research question is established:

How viable is the implementation of Automated Guided Vehicles within warehouses of express delivery companies?

Sub-research questions are drafted to structure the research and make it more easy to derive the answer to the main research question. The sub-research questions are based on the different factors which are identified to determine the overall viability. The literature review (chapter three) found that the viability can be determined by evaluating the technical, financial, regulatory and social-cultural environmental factors. The first sub-research question will give insight in the technical limitations of AGVs within express delivery companies. The following sub-research question is derived:

Question 1: What are the technical limitations of implementing AGVs within the processes of express delivery companies?

The second sub-research research question is related to the calculation method to determine financial viability. The following sub-research question is derived:

Question 2: How could the financial viability of an AGV implementation be determined in different warehouses?

The third sub-question is about the regulatory viability. The following sub-question is derived:

Question 3: What are the challenges to overcome in the implementation of AGVs with regard to the regulatory aspects?

The final sub-research question is about the social environmental viability. The following sub-research question is derived:

Question 4: What are the complications of the AGV implementation in the social environment?

1.4 THESIS STRUCTURE

The main goal of this research is to gain knowledge on the viability of AGVs in the warehouses of express delivery companies as described in this chapter. The second chapter discusses the research structure, the case study approach and which resources are used to answer the main research question. The third chapter elaborates on the used theories to determine the viability. Finally, the fourth chapter describes the results of the research.

2 RESEARCH METHODOLOGY

2.1 RESEARCH SCOPE

The research is focused on the non-conveyor process within the warehouses of express delivery companies. In the non-conveyor process pallets are processed by forklifts, which will be further explained in chapter four. The non-conveyor process is a process which is completely manual (labour intensive) and accidents happen often, as illustrated by Appendix XXVII. Furthermore, the non-conveyor process is currently the only process where AGVs could be technically and financially attractive, without changing the entire process structure within these enterprises. In the warehouses large conveyor sorting machines are used in the conveyor process. These systems can process 5000 packages per hour which would require many AGVs. The current warehouse would have to be changed completely and AGVs will be to expensive compared to the sorter. The client (TNT/FedEx) was therefore most interested in the viability of the non-conveyor process too.

2.2 RESEARCH FRAMEWORK

The research framework is developed to ensure that the research will be performed in a reliable way. The research framework is part of the research methodology and describes & schematically shows the logical steps that need to be followed to successfully achieve the objective of the research (Verschuren, 2010). This framework will be the foundation for the direction of the research. The required steps and theories to execute the research will be discussed below and are shown in the research framework in figure 2.

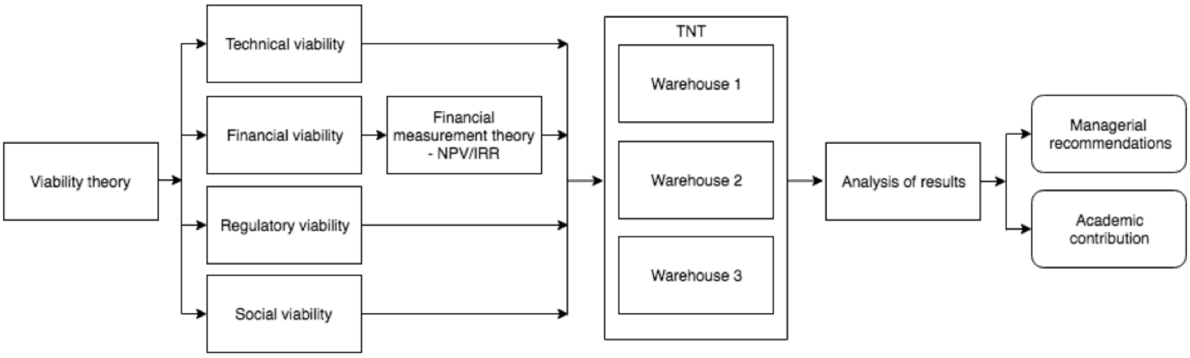

Figure 2 Research framework

The main goal of the research is to determine whether AGVs will be viable for use within the warehouses of express delivery companies. The first step of the research is to define how viability of an AGV implementation could be determined. Literature review identified four viability factors to determine the overall viability. These four viability factors are related to the technical, financial, regulatory and social viability as will be explained in chapter three. The viability will be determined through a multiple case study at the warehouses of TNT because case studies are able to obtain in-depth knowledge about specific cases (Cunningham, 1997). Furthermore, a multiple case study is chosen to increase the reliability and generalizability of the research as will be described in paragraph 2.3.1. The required information during the case study is mainly based on a qualitative research approach. Within the case study the technical, regulatory and social factors could be identified by qualitative methods such as interviews. However, the financial factors are important for decision-making within companies and are most commonly determined by quantitative methods (R.J. Gagnon, 1997). For this reason, financial viability theory is added to perform these calculations in the desired and scientific way. Eventually, the results of the different warehouses will be analysed and conclusions will be derived. Recommendations on the viability of such an implementation will be given for the express delivery companies. Moreover, the literature will be expanded with knowledge on viability of AGVs within express delivery companies and will identify new literature gaps concerning AGVs in express delivery companies.

2.3 CASE STUDY APPROACH

In the previous paragraph the research framework is given which describes the overall structure of the research. This paragraph will describe why a case study is chosen and how the case study will be executed to obtain reliable results.

2.3.1 Case study protocol

The research is dedicated to a multiple holistic case study because it has one unit of analysis evaluated in multiple warehouses. In case studies it is important to make use of a case study protocol because this is will guide and is the foundation for data collection (Yin, 2013). The case study protocol is divided in three important principles to guide and increase the reliability of the research. The three principles are: data collection procedure, case study question and data analysis procedure. These principles will be discussed in the following paragraphs. The negative implications of case studies are the lack of generalizability, inability to replicate and the subjectivity of the researcher. To increase the reliability and generalizability of the results a multiple case study is chosen.

In this research three different warehouses of the TNT side are chosen to investigate. This due to the limitation in accessibility of the warehouses of FedEx during the integration of TNT and FedEx (Catalin, 2018). The chosen warehouses differ in type, size and location. TNT has three different types of warehouses and these are chosen to gain more insight in the viability of different warehouses types. The chosen warehouses are located in Luik (air hub), Arnhem (road hub) and Eindhoven (depot/station). The warehouse in Luik is in Belgium while the other two are in the Netherlands which is expected to increase the generalizability of the results. The difference in size could be interesting because this will change the business case and research has shown that large warehouses seem to be less efficient than smaller ones (T. HACKMAN, 2001). The chosen warehouses are relatively large (more then 1000 pallets per day) because in smaller warehouses employees often have multiple tasks and an AGV could not perform these tasks. The warehouse must have a separate pallet process where the pallets are handled with forklifts.

Ad 1 Data collection procedure

In case studies information will be gathered mainly by qualitative methods such as interviews. The experts that will be interviewed are chosen strategically to secure that the obtained data is reliable. The goal is to achieve results concerning the technical, financial, regulatory and social viability. Furthermore, documentation and literature is used to achieve triangulation.

The required information to determine the technical viability of the AGV technology within the warehouses of delivery companies is obtained by interviewing warehouse experts and manufactures. Manufacturers have implemented these technologies in multiple industries and do know what the common limitations are. Therefore, it is very interesting to interview them. The chosen warehouse experts are a hub manager, process experts and a health & safety expert. The hub manager is chosen because of his or her extensive knowledge on management level. He or she should have knowledge about the future developments and problems in the processes and may mention other limitations than process experts. The process experts were chosen because they are directly engaged with the process and they know what the current problems are and what the possible limitations of AGVs could be. Eventually, the health and safety manager is chosen to obtain more knowledge on the regulatory aspect but is also asked for the expected limitations to obtain the opinion of someone without the technical experience.

The costs and performance information of AGVs will be obtained by interviews with manufactures. This information is necessary to determine the financial viability. These manufacturers are experts in implementing AGVs in multiple industries. The experts of manufactures are the only experts that have insight in the costs and performances of the AGV technology, which is crucial information for this research.

The required information concerning the regulatory viability will be obtained by interviewing the manufactures and the health & safety managers. The manufactures have much experience with implementations and know whether this could be a limitation. Furthermore, the health & safety managers are responsible for the safety of the processes and are responsible for the alignment with the laws within the warehouses.

The social environmental viability is determined by interviewing the process experts, hub managers and the health & safety experts. These experts have much experience with implementations of technologies in the past and should know the problems from the past. This applies to hub managers in particular.

Furthermore, four engineering experts were interviewed to obtain knowledge over the current process problems, AGV capabilities and limitations. These will be included in an additional paragraph. In table 1 the interviewees and their information supply factors are schematically given.

Table 1 Interview information

Interviews	**Technical viability**	**Financial viability**	**Regulatory viability**	**Social viability**
Manufactures	Yes	Yes	Yes	No
Hub managers	Yes	No	Yes	Yes
Process experts	Yes	No	Yes	Yes
Health and safety experts	Yes	No	Yes	Yes
Engineering department employees	Yes	No	No	No

Ad 2 Case study questions

The research is already divided in sub-research questions and these will answer the main research question. In this section underlying questions will be developed to answer the sub-questions. This to secure that the case study will be performed in a structured way which will also increase the reliability. Yin has classified the questions in different levels of gathering the information to structure what information should be gathered. level 1 and 2 are the empirical part where the information is gathered for the other parts. In table 2 are the sub-research questions divided in the categories to give answer on what data must be collected within the case study interviews. The case study questions are divided in sub-case study questions and are required to determine what information has to be obtained in the interviews. The sub-case study questions will be explained in this paragraph.

Table 2 Case study classification (Yin, 2013)

Sub-research questions	Level
2,3,4,5	1 Interviewees
4,5	2 Individual cases
2,4,5	3 Patterns of findings across multiple cases
2,3,4,5	4 Entire study
	5 Policy recommendations and conclusions

The first question aims to identify the non-conveyor process in particular to understand what the processes looks like and what the process objectives are. This information is necessary to determine the financial viability as well as to conduct the interviews in a reliable way. This information will be determined by internal documents. The case study questions can be found in table 3.

Table 3 Question 1

Question 1: What do the non-conveyor processes look like at the different warehouses?	**Sources**
What does the layout look like?	Documents
What are the main objectives?	Documents

The second question is about the technical viability. This part is divided in two sub-questions. The first one relates to the requirements of AGVs and is mapped by interviewing the manufactures and reviewing the documents of the manufactures. With the requirements the limitations could be determined. The second question is about the technical limitations of an AGV implementation and will be determined by interviewing the manufactures, warehouses and the engineering department. The related questions can be found in table 4.

Table 4 Question 2

Question 2: What are the technical limitations of implementing AGVs within the processes of express delivery companies?	**Sources**
What are the technical limitations?	Interviews with manufacturers, the warehouses and the engineering department
What are the requirements of the AGVs and forklifts?	Interviews with manufacturers Documents

The third question is about the financial viability. This information could not be determined by interviews because the suppliers also have to calculate this case-specific and could not provide a sustainable answer to the question whether AGVs are financially suitable in these processes. The financial viability therefore is determined by calculating the financial suitability for the three different warehouses. Therefore, cost measures had to be obtained concerning the costs of AGVs and forklifts. The difference in costs between the manual forklifts and AGVs will be the benefits. The costs of AGVs are determined by interviews with the manufactures and the current forklift costs by internal documents. The related questions can be found in table 5.

Table 5 Question 3

Question 3: How could the financial viability be determined in different scenarios?	**Sources**
What are the current costs values?	Interviews with manufacturers

What are the performance values of AGVs	Interviews with manufacturers
What are the costs of AGVs and forklifts?	Interviews with manufacturers Documents
What are the prominent advantages/disadvantages that could increase/decrease the financial viability?	Interview manufacturers and the of the warehouse

The fourth and fifth questions relate to the regulatory and social environmental viability. This will be determined by interviews with the process experts and the manufacturers. The related question can be found in table 6 and table 7.

Table 6 Question 4

Question 4: What are the challenges to overcome in the implementation of AGVs with regard to the regulatory aspects?	**Sources**
Are there any problems with the regulatory environment while implementing AGVs	Interviews with manufacturers and in the warehouses

Table 7 Question 5

Question 5: What are the complications of the AGV implementation in the social environment?	**Sources**
Are there any problems concerning the social environment while implementing AGVs?	Interviews with manufacturers and in the warehouses

As mentioned in the previous paragraph three different kind of interviews will take place and since the sub-case study question are defined the interviews could be prepared. These interviews consist of two parts. The interview with the manufacturers (the first part) is about the viability of AGVs and the second part is to determine the specific costs of forklifts and AGVs. This information is required to determine the financial viability. To determine the first part, a semi-structured interview method is used and for the second part fully-structured method is used. This is because the first part is meant to be more open ended and the second part is about specific values, such as the purchase price etc. The interviews with the warehouses and engineering department consist of the AGV part and the current process part and are both semi-structured. The interview questions are based on the case study questions that will be described in this paragraph. In appendix I the manufacturing interview can be found, in appendix II the interview of the warehouses and in appendix III the interview of engineering.

Ad 3 Data analysis procedure

The obtained information in the interviews has to be analysed in a structured way to guarantee the validity and reliability of the research. The interviews will be recorded, listened and described afterwards. In the semi-structured part of the interview only the important answers are written down. An answer in the interviews is important when it says something about the technical (requirements and limitations), financial, regulatory or social viability in any sense. In the structured interview part, answers will be written down directly because these questions will be about costs and need to be known specifically. The obtained data will be analysed and in this analysis all the found factors will be described and prioritized. The priority of the found factors will be identified by how important the interviewee defined the problem and by how many times it is mentioned. The saturation of the interview results will be measured to determine whether the amount of interviews was sufficient. In appendix IV an example is shown of how the analysis has have been done.

3 LITERATURE REVIEW

3.1 VIABILITY THEORY

The main goal of this research is to determine whether AGVs are viable for implementation in the warehouses of express delivery companies. To obtain this goal literature is reviewed, to find theory that describes how viability of a technology could be determined in a reliable way. The reviewed databases to find a theory that could determine the viability was googlescholar.com and sciencedirect.com, the used search terms were the following: technology viability, viability assessment theory, suitability of technologies, investment decision making theory, technology decision making, innovation theory, technology adoption barriers, technology adoption barriers in automation, adoption barriers Automated Guided Vehicle/AGV, technology appraisal, technology forecasting and many more. Only a few search terms led to proper theories and these were in the area of technology assessment (TA) and technology readiness.

The technology readiness level theory is developed by NASA to determine and test their equipment for orbit. In this theory the maturity of technology is only measured on the technical part, measures as costs and benefits in terms of financials are not incorporated. Commercial companies have to be competitive and keep their operating costs as low as possible which makes this theory alone not useful for this research.

TA is divided in different theories which include different tools and approaches to assess the viability or readiness of a technology. These tools and approaches are divided in public decision-making and business & non-governmental decision-making. Both the public and business decision-making approaches differ in objectives and evaluating criteria. The business decision-making approaches are taken into account in this research because the research is done for a business. The research of (Thien A. Tran, 2008) which reviewed 200 articles articles regarding the current TA approaches concluded that there is not a dominant method to determine the viability of a technology and even though TA developed over years it is still highly recommended to find more effective methods. Furthermore, they found that cost benefit analysis methods are most commonly used. The most commonly used financial measures in these approaches are the following: total savings, NPV, payback time, internal rate of return, accounting rate of return and total raw costs (R.J. Gagnon, 1997). These financial TA approaches are limited to the economical benefits and indirect effects are not even incorporated. Many TA practitioners criticized the different cost benefit analysis methods and modified the methods or used multiple approaches to evaluate the technology. Management of technology also states that technology change has to include more then only the economical aspects (Porter, 1991). To conclude, there is not yet a proper approach to determine the viability of a technology and the current models have to be modified or multiple approaches must be used. Further research found a paper that analysed many historical cases related to the pattern of the commercialization of high-tech products and identified a list of factors that could be a barrier to the large-scale diffusion of new high tech products. These factors will be used to identify the viability of AGVs within express delivery companies. To better understand why these factors will be leading to determine the viability more information about the innovation process of high-tech products will provided first.

The theory of Rogers (Rogers, 2003) states that the diffusion of a product follows a perfect S-shape pattern (in terms of adoption versus time). In this theory is assumed that the product is not changing over the life cycle (no product development in the diffusion process). However, UtterBack and Abernathy (Abernathy W.J., 1978) found that this model is too generic and does not hold for high-tech products. They found that innovations take place within the diffusion process and radical product innovations took place in the early phases whereas the incremental product innovations took place in later phases. This resulted in the distinction between radical and incremental innovation and led to a changed life cycle pattern (Abernathy W.J., 1978) (Tushman M.L., 1986) (Rosenkopf, 1992). Furthermore, Ortt and Schoorsman (Ortt J. a., 2004) came up with a product life cycle model where the innovation is even distinguished in three phases namely: innovation, adaption and stabilization phase. This can be seen in figure 3. In this figure is illustrated how high-tech products develop during their life. Multiple niches appear and disappear which means that the product or the circumstances is continuous changing and is not sufficient enough yet to diffuse on a large scale.

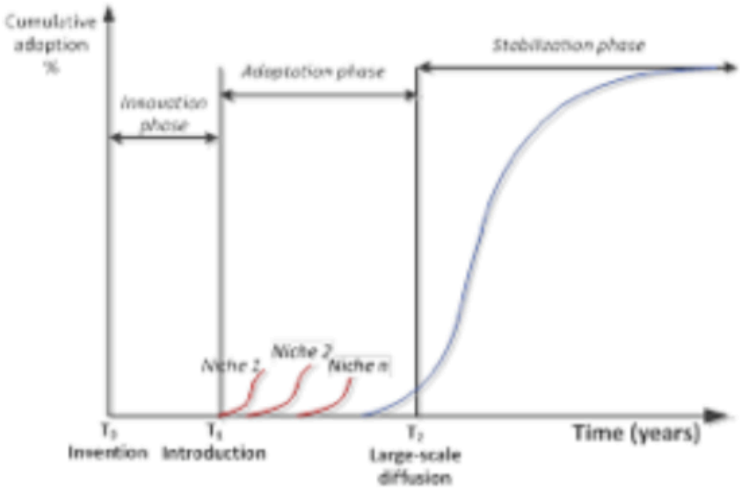

Figure 3 Innovation cycle (J. Roland Ortt, 2018)

The research of (J. Roland Ortt, 2018) found different factors/barriers that hampered large scale adoption. If AGVs are not viable for companies, they will never diffuse on a large scale because they will not be implemented by companies. This means that the identified barriers must also include the main viability factors for implementation. Twelve factors were identified as barriers for large scale diffusion and can be seen in table 8. The first six factors are the core factors and the last six the influencing factors. Meaning that the last six factors could be the reason why one of the first six factors is a barrier at that moment. These factors are important for large scale diffusion, but are not all relevant for the determination of the viability for a company to implement technologies. Therefore, this model must be modified and it will be investigated whether the twelve factors influence the viability. In table 8 are the factors and their description are given (J. Roland Ortt, 2018) and whether, how and why they are included in the research to determine the viability. The New high-tech product, Institutional aspects, socio-cultural factors are the ones that are interesting for determining the viability of AGVs in this case. The new high-tech product contains the financial and technical viability. Furthermore, the institutional and socio-cultural factors determine whether the regulations and social environment is ready to accept the technology. Complementary products and services and accidents or events could also impact the viability. However, these do not have impact on the viability at this moment because there are not yet negative events within this field. Moreover, complementary products and services do not play a role because the forklifts and AGVs do not have complementary goods and the service contracts are the same. The residual factors are not relevant because they are specifically focused on large scale diffusion Thus, the important factors to determine the viability are the technical, financial, regulatory and social viability. If these are viable the technology in general will be viable for implementation.

Table 8 Factors for large-scale diffusion (J. Roland Ortt, 2018)

Factors	Description	Factor acceptance	Factor type
New high-tech product	This factor distinguishes the product in three elements: The technical principles used, functionalities provided and the main components in the system. If one of these principles in unavailable, the product is not ready for large-scale diffusion. The product must has to have good price/quality compared to other products/technologies. This means	This factor describes that the price/quality and technical functionalities must be good in comparison with other technologies. Otherwise, these technologies will not be used on a large-scale. This factor directly determines whether companies would implement a technology and is therefore an important factor to include in this	Financial and technical viability factors.

	that the product must be financially and technically attractive.	research where the viability of such a technology will be determined.	
Production system	This factor describes the importance of a production system. The supply of products must be sufficient for large-scale diffusion. In some cases, products are craftsmanship and no industrial production technology is available. In this case large scale diffusion cannot take place.	This factor describes the importance of a good production system. This is not relevant for the research where the viability of a technology for a company will be determined. There are many suppliers that offer such AGV applications and are available for implementation in a warehouse.	-
Complementary products and services	The complementary products and services relate to the services required to produce, distribute, adopt and use the product. The unavailability of one of the aspects means that large-scale diffusion is not possible.	The complementary goods are important to the customer. In the preliminarily research it was found that there are no complementary goods for these trucks and the service agreements are the same. Therefore, this factor will not be further researched.	-
Suppliers (network of organizations)	The suppliers and producers relate to the actors that have stake in the supply of the product. The network between the suppliers, producers and other actors with considerable resources must be in place. If one of these actors, resources or coordination is not present large-scale diffusion is blocked.	This factor is not relevant for determining the viability of the product in the view of the customer. The customer must be sure that the product could be supplied and how the suppliers does that does not matter.	-
Customers	The customers have to be knowledgeable about the applications and the product itself. The customer has to be willing to pay for the product and if they are not aware of the benefits they will not implement such a technology.	This aspect determines whether customers are knowledgeable of the technology and willing to pay for it. This could be a limitation for large-scale diffusion but not for the viability determination for the customer. In this research it will be discussed whether customers are willing to pay and implement such a technology.	-
Institutional aspects (laws, rules and standards)	The institutional aspects refer to the regulatory environment. Laws and regulations could stimulate or completely block the use of such a technology.	This factor is important in the determination of the viability of a technology. If the laws prohibit the use of such a technology it will not be viable for the industry.	Regulatory viability factor.
Knowledge of technology	The knowledge of technology relates to the capability to develop, produce, replicate and control the technology. A system that lacks knowledge concerning these aspects block large-scale diffusion.	This factor relates to the possibility to reproduce the product. This is an important aspect to achieve large-scale diffusion and is not determining the	-

		viability for a single company. This factor is not included to determine the viability.	
Natural resources and labour	A lack of resources and labour in the production system results in the unavailability of large-scale diffusion.	The lack of resources and labour in the production system does not matter for the customer. As long as the product can be delivered this will not be a problem for the customer. This factor is not relevant for the viability determination.	-
Knowledge of application	If producers and customers have insufficient knowledge about practical applications of a technology, large-scale diffusion will be blocked.	This factor is not relevant for this research. The research is even giving insight in this factor.	-
Socio-cultural aspects	The social-cultural factors relate to the norms and values in a culture. These could be norms and laws. Both could lead to a complete block of large-scale diffusion.	This factor is important to determine the viability. The norms and values have to accept the technology before it could be implemented. Trade-unions for example have to accept the technology to reduce the risk of possible strikes. This factor will be included to determine the viability.	Social environmental viability factor.
Macro-economic aspects	The macro economic status could influence the large-scale adoption. In times of recession this could block the large-scale diffusion.	This factor is also important to determine whether such technologies are viable. As mentioned in the problem analysis companies are very interested in such technologies and are willing to invest. This factor will not be further researched.	-
Accidents or events	Accidents within the use of the product or events such as war can have devastating effects on the diffusion of high-tech products. This could stimulate or block large-scale diffusion.	This factor could have impact on the viability of such a technology. However, initial research found that there are not yet any concerns on this part.	-

3.2 FINANCIAL VIABILITY THEORY

The previous paragraph described the most important factors to evaluate the viability of high-tech products and one of these factors is the financial viability. The financial viability is hard to identify by qualitative methods and is usually calculated by financial-decision making measures (R.J. Gagnon, 1997). This paragraph will elaborate on the most commonly used financial-decision making measures.

Before starting a project, a viability study is conducted to estimate the feasibility of achieving the project goals. The cost and benefits of investing in such a project are most often evaluated (Rijnen, 2017) and the project will be chosen, when the benefits outweigh the estimated costs. Researchers Ye & Tiong (Ye, 2000) analysed a large variety of tools that are used in decision making within projects. The ones that they identified were the net present value (NPV), the internal rate of return (IRR), return on investment (ROI) and the payback period is used too (Alkaraan, 2006). The NPV method is mostly applied in practice and is commonly chosen in academic literature (Tziralis, 2009) (Van der

Lande, 2008). Additionally, within TNT/FedEx every significant capital expenditure has to be approved in a capital expenditure description (CAPEX) by the board (TNT/FedEx, Europe Capital Approval Process Alignment Training , 2017). The CAPEX consists of the explanation of the costs & benefits. The used method to explain the costs & benefits within TNT/FedEx is the NPV and IRR. However, in this paragraph all the decision measures will be described to give more insight in the methods.

The Net Present Value (NPV) is the difference in present value of cash inflows and the present value outflows over the project period. The NPV is used to analyse the profitability of investing in a project. In general projects with a positive NPV will be accepted. In case of different projects, the one with the highest NPV will be chosen (Bas, 2013) (CONEJOS, 2015). To calculate the NPV the cash inflows and outflows have to be known. Cash inflows and outflows are specified by the costs and benefits of the technology.

Within the NPV formula the cost and benefits of the AGV/forklift theory will be compared based on the mentioned costs. The NPV formula can be seen in figure 4.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Figure 4 NPV Formula (Investopia, 2018)

In the NPV formula the yearly net benefits (Ct) will be calculated for every single year over the lifespan of the project. These yearly costs will be discounted by the weighted average cost of capital (WACC) given as r in the formula. Afterwards these yearly costs will be summed and settled with the investments costs (Co). This results in the net profit over the lifecycle of the project. The WACC formula compensates the costs of interest for taxes (Miles, 1980). For this reason, the cash flows used in the NPV formula should also be adjusted for taxes (Berk, 2013). This means that all the costs of the AGV and forklift have to be compensated for taxes.

The internal rate of return (IRR) determines the profitability of investments by setting the NPV at zero with a variable WACC rate. The formula of the NPV and IRR are completely the same. This gives another vision on the profitability then the NPV because an increasing WACC will have different impacts on the different projects. The project with the highest IRR is likely to be chosen (Bas, 2013). In the following chapter the viability and financial viability theory will be applied to evaluate the viability of AGVs in the three different warehouses.

4 RESULTS

In this chapter the viability will be determined for the three chosen warehouses by using the viability factors identified in chapter three. In the early phase of the research is found that AGVs are too slow to load and unload trucks compared to manual forklifts (Ullrich, 2015). In the case study every interviewee verified that loading and unloading is not yet possible by AGVs. The AGVs cannot stack different unregular pallets and they are way too slow while the loading and unloading speed is crucial for an express delivery company. For this reason, the potential of AGVs will be investigated in the transport part of the non-conveyor process.

The information provision of the first two warehouses and the manufacturers was already saturating. Therefore, in the last warehouse only one interview and observation are conducted. The findings from this interview were similar to the findings in the other warehouses. Furthermore, three interviews were performed in the warehouses of Arnhem but one of the interviews is not considered. Unfortunately, one of the interviews was very short because the interviewee was not familiar with automation. The remaining two interviews were conducted with two experienced employees in the hub in Arnhem.

4.1 TECHNICAL VIABILITY

The technical viability is one of the factors to determine the overall viability and will be determined for the three different warehouses in this paragraph. The data collection procedure in the previous chapter mentioned that the technical limitations will be identified by asking the manufacturers and warehouse experts. However, in the interviews with the warehouse experts it turned out that the warehouse experts did not know enough about the AGV technology to identify reliable technical limitations. The manufacturers did not know much about the processes of express delivery companies but they had a lot of implementation experience in other industries and could mention main limiting requirements. The limiting requirements are factors that could limit the implementation of an AGV system. For this reason, the technical viability analysis changed. The main limiting requirements mentioned by the manufacturers were tested in the warehouses by observation. The expected additional limitations obtained by interviewing the process experts are mentioned additionally. This made the results even more interesting because it has been obtained by making use of multiple methods. In the first paragraph the differences between the AGV applications will be described to understand why the technical limitations could differ between the applications. The second paragraph describes the limiting requirements found by the manufacturers and in the following paragraphs these limiting requirements will be evaluated for the different warehouses.

4.1.1 Differences between AGV types

In this paragraph the differences between the AGV applications will be described. This information is relevant to be able to determine the different limitations of different applications. Two AGV applications were found to be useful within express delivery companies in literature and within the interviews at the manufacturers these are the conveyor/piggyback type and the original AGV forklift type. The description of these two applications can be seen in appendix V. In table 9 the differences of the forklift and conveyor AGV are given based on the research of Ullrich. The most important differences between the forklift and conveyor AGV in the warehouses of express delivery companies will be highlighted. The identified important differences found by observation and interviews with the manufacturers were: difference in lifting the pallets from the ground, time required for load handling, space requirements and the pallet handling range (appendix IX). The difference in lifting the pallets from the ground is an important aspect because conveyor tables must be implemented for the AGV conveyor type which could have implications for the viability. The time required for load handling could also impact the viability since AGV conveyors are faster. The space requirements could differ because the AGV forklift has to pick the pallets in the driving direction which could require more space. The last important difference is that the forklift can only pick up a limited number of pallets in a process with many different pallet types while the conveyor type could pick up every pallet which is within the dimensions of the conveyor (Ullrich, 2015).

Table 9 Characteristics of AGV forklift and conveyor (Ullrich, 2015)

Technical characteristics	Piggyback/conveyor AGV	Forklift AGV
Lifting pallets directly from floor	Not possible	Possible
Stacking pallets	Not possible	Possible
Space and time required for load handling	Low: can be positioned in the drive path with lateral load transfer.	High: load transfer must be done along axis of drive path.
Driving speed	Top speed on long straight lanes up to around 2 m/s	Same as conveyor type
Suspension kinematics	All variants can be used	Classic three-wheel construction
Navigation equipment	Current systems	Current systems
Space required for layout	Only slightly larger than the load itself	Considerably larger than the load, especially in the counterweight version
Manual operations	Barely possible	Possible under circumstances, depends on the model and make
Flexibility of use	High	Very high, as no stationary conveyor is needed

4.1.2 Technical viability results manufacturers

The manufacturers could not answer whether the AGV technology will be financially viable within express delivery companies because this is very case specific. They could answer what the general limitations and or the limiting requirements of AGVs are. The following limiting requirements were identified by the analysis of the interviews:

- **Predefined area.** Meaning that the pallets have to be placed in a particular place within the specified limitations of the technology. The conveyor application even requires a conveyor pick-up location;
- **Predefined pallets.** The pallet has to be predefined in advance. Otherwise, the AGV does not know how it has to pick it up. Furthermore, the pallet has to be within particular dimensions; otherwise it will not operate either. The conveyor type does not have this requirement, but the product has to be within specific dimensions;
- **Required space.** The performance of AGVs are lower compared to the manual forklifts and it is sometimes required to have another lane for manual forklifts and AGVs. In many cases extra space is required;
- **Mixed traffic.** The operation of AGVs and manual forklifts is possible. However, the forklift drivers have to respect some traffic rules. This could be a limitation;
- **Clean floor.** The floor has to be clean otherwise the AGV will stop and the dirt will first have to be removed;
- **Loading and unloading.** Loading and unloading is in many cases impossible or very slow. This will not be viable in a process where many products have to be processed in a specific time;
- **Floor specifications.** The specifications of the floor have to comply with the floor specifications of AGVs;
- **Wi-Fi.** Wi-Fi connection is required for communication;
- **AGV portfolio.** Not every kind of forklift is supplied. The forklifts that are used in the warehouses are types that are supplied at every AGV manufacturer.

The floor specifications, Wi-Fi and AGV portfolio are not a significant problem in any of the warehouses. The other five requirements will be evaluated in the three different warehouses to determine whether these requirements are also limitations within the warehouses of express delivery companies. These limiting requirements were mentioned in appendix (VI, VII, VIII and IX) and the analysis can be found in appendix

X. In the first interview, eight out of the nine limiting requirements were mentioned. In the third interview only one other limitation was mentioned. This means that the interviews were saturated as can be seen in appendix XI.

4.1.3 Technical viability of the warehouse in Luik

In the introduction is already found that loading and unloading could not be done by AGVs. Therefore, the transport part in the non-conveyor process will be analysed. In this process the pallets will be transported from the loading ore unloading sides to the other loading or unloading sides. The warehouse in Luik is an air-hub which means that the process has to comply with the rules of airports. This means that pallets that arrive from the road side have to be scanned in an X-ray machine. After the scan they will come on the airside and they have to be transported to the destination in one of the loading areas. The X-ray machine make use of a conveyor which can be seen in appendix XII. The pallets that arrive at the airside (from the aircraft) will be redistributed to other flights or brought to the loading part of the trucks. Most of the pallets from the airside will be loaded into the trucks to be further distributed. The main limiting requirements were identified in paragraph 4.2.1. These limiting requirements will be evaluated in this paragraph to determine whether this will be a limitation. The expected limitations identified by the warehouse experts will be mentioned too.

Mixed traffic. Mixed traffic is not a problem if the employees are willing to cooperate with AGVs (Ullrich, 2015). This is important because the manual forklifts have to comply with the rules of the AGVS. However, in a process with time pressure and many forklifts it is recommended to separate these lanes. Every interviewee recommended separate lanes. In this case it is assumed to be required to separate the lanes

Required space. The process of transporting pallets in the non-conveyor process requires a lot of space and there is not much room left. Implementing AGVs will be hard because more AGVs will be required and a separate lane is recommended. There is no room for another drivers' lane. In this warehouse the space will be a limitation. in appendix XII a part of the process can be seen.

Predefined area. The process in Luik consist of different parts as mentioned in the process description. The pallets have to be taken from the X-ray machine and from the ground at the unloading side of the airside. At the X-ray machine the place of the pallets is predefined but not specific enough. The AGV forklift pick up location has to be defined with a margin of a few centimetres. In appendix XII it can be seen that this is impossible in the current setting. Furthermore, the conveyor application could be viable for this part because it needs such a conveyor to be able to pick the pallets. The other part is picking up pallets from the ground in the unloading side of the airside. These pallets are placed randomly and there are no predefined areas. It will be hard for forklift drivers to put time precisely in a specific area because they have time pressure. Another limitation is the fact that the pallets have to be picked up in the load/unload area while there is not much space, and this could lead to problems in the collaboration between an AGV and manual forklift. Extending the building to overcome this problem is not an option because the building then has to be expanded in the direction of the building which makes the drive distances too long and the building to expensive. This results in the fact that some kind of conveyor table has to be placed in the buffer area. This table will move the pallets from the load/unload side to the place where the AGV could pick them up. The conveyor AGV is more efficient and could handle more different pallets when a conveyor table is installed, and this makes the AGV forklift unnecessary for further research.

Predefined pallets. TNT has no strict rules on pallet requirements within their policy. Many pallet types are processed, even home-made pallets/boxes and other kind of products are handled. In appendix XII a number of different pallets can be seen. The different kind of pallets is one of the major problems for the forklift AGV. Every single pallet has to be defined; otherwise the AGV cannot pick this pallet and the products on the pallets also have to be within particular dimension and have to be measured before the pallet is taken. This result in the fact that only a percentage of the pallets can be taken by the AGV forklift and that these pallets have to be measured beforehand. The conveyor AGV does not require predefined pallets. The pallets have to be within specific dimensions because the conveyor can only pick up pallets/boxes that are within the conveyor dimensions.

Clean floor. The floor is not always clean since pallets occasionally break, which could be a limitation for AGV forklifts. This is also due to the lack in pallet requirements. The conveyor AGV will not have this problem because it will drive on a different lane and the pallets will not break because they are not on forks anymore.

The hub manager, process experts and H & S manager mentioned the first four limitations too. The process has many exceptions, no standard pallets, the pallet quality is sometimes bad, and it could be hard to combine humans and machines. Furthermore, they mentioned that it could be a challenge to read the labels for the location identification and the changing buffer areas, which is not possible anymore with predefined locations. The interviews can be found in appendix (XXI, XXII, XXIII).

4.1.4 Technical viability of the warehouse in Arnhem

The warehouse in Arnhem is a road-hub. In road-hubs the pallets only have to be transported from buffer to buffer. The warehouse in Arnhem also receives packages directly from the depot. The unloading part is in the middle of the building. The logic behind this is to decrease the travel distance between the unloading and loading side. Packages will be picked at the inbound part from the depot and unloading part which will be distributed to the loading parts. In paragraph 4.2.1 the main limiting requirements were identified. These requirements will be evaluated within this warehouse. Furthermore, expected limitations of the experts in the warehouses were identified. The interviews can be found in appendix (XXIV, XXV).

Mixed traffic. Mixed traffic is not a problem if the employees are willing to cooperate with AGVs. However, it is recommended to separate driving lanes.

Required space. In this warehouse it is very busy, and it is questionable whether AGVs could fit in the area. This could be a limitation because many more AGVs are required due to the performance of the AGVs. It is also recommended to separate the AGVs from the manual forklifts which is not possible in here due to space limitations. The limited space could be seen in appendix XIII.

Predefined area. There are no predefined areas for the pallets. This is even hard to implement in the warehouses because the loading and unloading of trucks has high time pressure. These drivers are not able to put every pallet perfect in a predefined area. The picture of the buffer area can be seen in appendix XIII.

Predefined pallets. TNT has no strict rules on pallet requirements. For this reason, different sorts of pallets enter the warehouses. Even home made pallets/boxes. So, it is nearly impossible to predefine the pallets. Still same network so same pallets but just another example of the difference in pallets.

Clean floor. This is not always the case due to the bad quality of the pallets. This could be a limitation because it could lead to deadlocks for the AGVs.

The warehouse experts mentioned the space limitations and different kind of pallets as biggest problem for automation.

4.1.5 Technical viability of the warehouse in Eindhoven

The warehouse in Eindhoven is a very large depot and has a separated non-conveyor process. In this process the pallets first have to be weighted and dimensioned which is different from the hub process. Furthermore, the unloader directly transports the pallets to the check weight cube (cwc) instead of making use of a buffer. AGVs could only be used from the cwc to the buffer area of the loading side. Moreover, in this process trucks are unloaded by man riders instead of forklifts. One of the implications of using man riders is that they could not lift pallets higher than a few centimetres.

Mixed traffic. In this case mixed traffic could be possible. This is because only a couple of AGVs and forklifts have to collaborate while the drive way's width is five meters.

Required space. The space is very limited in peak times. Pallets are sometimes placed on the drive ways which makes it impossible for AGVs to operate.

Predefined area. One of the additional limitations in this case is the fact that the cwc are on the ground level and this could not be changed since the man riders cannot lift the pallets. This means that the conveyor application cannot be used as long they use man riders. The forklift application cannot be used as mentioned in the Luik case.

Predefined pallets. The same results are presented as with the Luik and Arnhem case. In the appendix XIII the different pallets can be seen.

Clean floor. Same results are presented as with the Luik and Arnhem case.

Following the interviewee within the warehouse the biggest limitation is concerns the available space. The interview can be found in appendix (XXVI).

4.1.6 Technical viability analysis

The findings concerning the technical viability of the three warehouses will be further explained in this paragraph and general conclusions will be derived. The main conclusions are that the AGV conveyor type can be used in new or expanded warehouses under certain conditions and only a percentage of the volumes can be automated.

The objectives of the non-conveyor process within the three warehouses were the same. The execution of the process, however, differs between the three warehouses. The air hub has an additional process step where a part of the pallets has to be scanned by the X-ray machine. The road hub is only distributing the pallets from buffer to buffer and the depot in Eindhoven does not have a buffer to buffer process. The depot in Eindhoven have to weight and determine the dimensions of the pallets and therefore have a check weight cub in the middle of the process. The unloaders directly bring the pallets to this cwc. They also use man riders which cannot lift pallets higher than a number of centimetres. These differences in the processes led to different results in the case of Eindhoven. In the process of Eindhoven AGV conveyors could only be used when the cwc is adjusted with a conveyor and this make it impossible to use man riders at these cwcs. This does not make it impossible but in the financial analysis this has to be taken into account.

Both the AGV conveyor and AGV forklift type are not technically viable if the warehouse will not be expanded or a new warehouse would be build. In all the current warehouses was found that there is not enough space to implement the AGVs. This because of lower performance of AGVs and the recommended separated lane for the AGVs. One of the major requirements is the predefined area. It will be necessary for the AGV forklifts as well as for the conveyor application to implement a conveyor table to pick up the pallets. This is required for the conveyor type because it cannot pick up the pallets in any other way. The forklift and conveyor AGV also need such a system because otherwise they have to drive in the area of the loader/unloader which will result in problems. This conveyor table makes the forklift application useless since the AGV conveyor its performance is way higher and could process a larger range of pallets. This due to the fact that the dimensions of pallets only have to be in a particular range for the conveyor type and for the AGV forklift type the pallets and load have to be predefined which is nearly impossible due to the large variety. Dirt on the floor could also be a problem. The pallet quality is low, and this results in broken pallets sometimes. If this happens, an AGV forklift will stop whereas a manual forklift driver could handle this situation which could be a limitation. The conveyor type has less change of damaged pallets because the pallets will be put on a conveyor with a better force spreading. The conveyor type could not pick up all pallets either because they have to be in particular dimensions. In table 10 the limitations in the current warehouses are given.

Table 10 AGV limitations current warehouse

	Warehouse Luik	**Warehouse Arnhem**	**Warehouse Eindhoven**
Limitations of AGVs in current warehouses	Mixed traffic	Mixed traffic	Required space
	Predefined area	Predefined area	Predefined pallets
	Predefined pallets	Predefined pallets	Dirt on floor
	Dirt on floor	Dirt on floor	

In new or expanded warehouses, it is still not viable for forklift AGVs because it is very inefficient compared to the conveyor type. The forklift AGV is slower, can processes less pallet types and has a higher risk of dirt on the floor while the requirements of implementation are the same as the of the conveyor. The conveyor type could be implemented in a new or expanded warehouses in which the conveyor tables will be installed and separated lanes for the AGVs could be made. The separate lanes will reduce the mixed traffic challenge and the conveyor table will be the solution for the predefined pallets and area because the pallet location is already predefined, and the pallet do not have to be predefined anymore. The only requirement is that the pallets are within the size of the AGV conveyor regardless of the pallet type. Also, the dirt on the floor will be reduced because the pallets will not break anymore on the conveyor AGV. In the network of TNT, it is assumed that still about 50% of the pallets is within the range of the conveyor and means that the other 50% still has to be handled manually. The human interaction has to be determined on each case because they could work together if the employees are willing to do so (Ullrich, 2015). Otherwise, separate lanes for the AGVs have to be implemented. The research found that the separation for example is not necessary in the warehouse in Eindhoven. In Eindhoven only a few AGV and manual forklifts will operate while there is plenty of space due to the rule which is used in the design phase. The rule is a drive way of 5 meters' width and as long as the building is which means that there is plenty of space in a process where they handle only a few products. In table 11 the limitations and conditions of the AGV conveyor could be seen in a new or expanded warehouse. In the warehouse of Eindhoven, it could be the case that the man rider's correction is making the business case negative which would result in the fact that AGVs are only useful in the hubs which are bigger and have a buffer to buffer process. To conclude, technically is the AGV conveyor is viable. To determine the overall viability, also the financial, regulatory and social viability have to be determined which will be described in the next paragraphs.

Table 11 Limitations and conditions new or expanded warehouses

Limitations in new or expanded warehouses	**Warehouse Luik**	**Warehouse Arnhem**	**Warehouse Eindhoven**
Conveyor AGV	Non, but the conditions are: - Conveyor table - Separate lane	Non, but the conditions are: - Conveyor table - Separate lane	- Man riders are used Conditions: - Conveyor table and adjusted cwcs

4.2 FINANCIAL VIABILITY

4.2.1 Financial viability calculation model

Ad 1 CALCULATION MODEL IN GENERAL

In the previous chapter the technical viability is discussed. The technically analysis found that the AGV conveyor type is technical viable in the transport part of the non-conveyor process in new or expanded warehouses because the current warehouses are too limited in their available space. In this paragraph the financial viability of implementing these AGVs in one of the warehouses will be determined. This will be done by evaluating the current warehouses with the adjusted requirements (extra area for example). This analysis is done to determine whether AGVs are viable for use in the warehouse of express delivery companies with as main goal to determine whether these companies have to further research the AGV technology.

Financial viability theory is reviewed to define a method to calculate the financial viability since this could not be estimated by any experts. The main financial measure found is the NPV value method which is explained in the literature review. Within TNT/FedEx every significant capital expenditure has to be approved in a capital expenditure description (CAPEX) by the board of TNT/FedEx (TNT/FedEx, Europe Capital Approval Process Alignment Training , 2017). The CAPEX elaborates the costs & benefits of an investment by evaluating the NPV and IRR. TNT/FedEx demanded a model with the capabilities to determine the general financial viability of AGVs compared to the current forklifts in different warehouses of the TNT/FedEx. A calculation model is made based on the financial viability measures explained in the literature review. The financial viability is an important measure for companies to invest in technologies. This paragraph will describe how to model works and in the following paragraphs it will be applied.

The NPV method compares the present costs and benefits of an investment over a certain time. In this research are the benefits are the cost savings of the AGV compared to the manually used forklifts. This means that the AGV and manual forklift costs per year will be identified and compensated for each other to determine the NPV of the AGV technology. The costs of both the AGV and manual forklifts first have to be measured. The important cost measures of these technologies are identified by literature and verified by the interviews with the manufacturers and warehouse employees. The costs of forklifts and AGVs are divided in direct, indirect and investment costs and will be explained. Moreover, additional indirect benefits are identified in literature. These benefits are analysed in the case study but were not taken into account in the business case because advanced automation effects could be non-pecuniary or indirect and hard to quantify (KULITILAKA, 1984). The direct costs can be found in table 12. In this table building costs are added because it is likely that the building has to be expanded, which is not yet taken into account in the literature.

Table 12 Direct costs (Ullrich, 2015)

Position	Description
Maintenance	The steady and low-impact driving minimizes wear on wheels, batteries and drives
Energy	Basically, the share of charging energy for the AGVs
Operating personnel	Only relates to transport system; guidance control personnel only
Transport damages to product	Automated transport minimizes transport damages. Material additional work and reworking, and customer damage claims are to be considered
Transport damage to plant fixtures	Such as loading aids, pillars, walls, shelves and gates
Building extension costs	It could be that more space is required while implementing AGVs

The indirect costs relate to the costs made to make the AGV able to operate and these costs are case specific. An example could be the reduction in buffer area. In table 13 the indirect costs are shown.

Table 13 Indirect costs (Ullrich, 2015)

Position	Description
Personnel costs in neighbouring areas	If needed, forklift operators, personnel to make pallets available and for fine distribution
Warehouse inventory	Inventories can be reduced through improvements to information flow and high availability
Material inventories in manufacturing	-
Throughput time	Ordering time can be reduced and the order density increased - increasing effectiveness of production

The investment costs are divided in multiple cost aspects and are given in table 14.

Table 14 Investment costs (Ullrich, 2015)

Position	Description
AGVs	Vehicle, guidance control system, floor installations, project-related services
System periphery	Load transfer stations, buffers, to the extent that they are calculated as part of the AGVs and not the stationary conveyor equipment
Construction measures	Floor repairs, protective equipment, adapting fire doors, bridges and ramps
Integrating into existing structures	Interfaces to parallel, subordinate or overriding guidance controls, integration of automatic scales, scanners, etc.

To conclude, the used costs to compare the AGV and manual forklift are the following:

- Labour
- Building
- Energy
- Maintenance
- Purchase
- Other yearly costs
- Other investment costs

These costs are based on the literature and are verified by the interviews with the manufacturers and warehouse employees. The labour, building, energy, maintenance and purchase costs are straight forward. The other yearly cost and other investment cost could entail many elements. The yearly costs could for example include the costs of damages. The other investment costs could for example contain the installation costs of the system. After the identification of the cost types the decision measures could be calculated. The model includes the main decision criteria that are most frequently used in literature as well as in TNT/FedEx. These are the Net Present Value (NPV) and the Internal rate of return (IRR). Furthermore, as mentioned in the literature study, there are also other decision criteria, such as the Return on Investment (ROI) and Payback rule, which are also included in the model as addition. These measures together make it possible to determine whether AGVs are more financially viable than the manual forklifts. As described in the literature review an investment is following the NPV decision rule acceptable when the NPV is higher then zero. If multiple cases have to be compared the one with the highest NPV has to be chosen. Within TNT/FedEx also the IRR is considered. The IRR is the point where the WACC (discount rate) is so high that the NPV will be zero. The WACC describes what the costs of capital are and that the results of investment have to be higher than the WACC otherwise they will lose money on the project. If the IRR is close to the WACC the risk of losing money is more likely. Furthermore, the additional benefits are not taken into account in the business case while these could have a large impact. These aspects make it hard to give a good estimation on the financial viability and could also be the reason why investment decisions are guided by experience or management instinct (Bondt W, 2013).

The model can determine the financial viability in different scenarios. Every price and warehouse performance measure can be changed. The model is checked by determining three random scenarios by hand. These calculations gave the same results.

Ad 2 Inputs & found values

In this paragraph the required input values of the model will be discussed as well as the found values which are applicable for the model in every scenario at this moment for TNT/FedEx. The required input values are divided in two parts; namely: the general values and the performance values of forklifts and AGVs. The input variables and the found values will be described for the mentioned variables. The input variables which are not described yet will be described within the case study because they are cases dependent. The input layout sheet can be found in appendix XVII.

The general input variables are the following:

- Average volume per hour. This measure entails the average volumes of pallets in a particular warehouse. This measure is case specific;
- Peak volume. This measure entails the highest volume peak that appeared in the same period of the average volume;
- Average peak time in hours. As mentioned in the description of the model the average peak hours have to be determined. This contains for how many hours the peak volume is there;
- Labour costs of forklift drivers. This measure is case specific;
- Building costs per square meter. These costs are assumed to be 200 euros per square meter per year (Benelux, 2018);
- The WACC. The WACC is every year calculated by the finance department of TNT/FedEx, the value for 2018 is approximately 9% (manager, 2018);
- Inflation rate. The inflation rate in 2018 the European union is approximately 2% (manager, 2018);
- Tax rate. The tax rate used in the calculations is 25%. This rate is advised as assumption by the senior tax manager within TNT/FedEx;
- Amount of stops in the process. The process could have multiple stops where the forklift/AGV has to drop the pallet (example is weight and dimensioning). This can have impact on the financial suitability. The number of stops is case specific;
- Working hours per day. This measure is case specific;
- Working days per year. This is case specific;
- Energy cost per Kwh. This measure is assumed to be 0.12 euros per kWh (TNT/FedEx, 2018);
- Average driving distance for the forklifts. This measure is case specific;
- Contract flexibility. The contract flexibility can be answered with yes or no. If the contracts are flexible the labour cost for the extra employees required in the peak moments are only paid for the number of peak hours they work. In many countries are the contracts not flexible and the drivers have to be hired for a particular number of hours. In this research it is assumed that the labour contracts are not flexible and that they have to be hired for the complete shift.

The performance inputs for the forklifts as well as the AGVs are the following:

- Energy usage in Kwh per hour. There is no significant difference in energy use (appendix XVI). The energy usage on average is assumed to be 4,5 Kwh per hour (Renquist, 2012);
- The yearly maintenance costs. The yearly maintenance costs assumed to be 30% lower for AGVs compared to the conventional forklifts (appendix XVI). The average yearly maintenance costs for forklifts are approximately 3000 euros (TNT/FedEx, 2018). This will be 2100 euros for AGVs in this case;
- Economical life cycle in years. The economic lifecycle is very different per manufacture; it could range from 10-20 years for an AGV. In this research the worst case is taken. This is ten years. The economic life cycle of forklifts is assumed to be five years (TNT/FedEx, 2018);
- The purchase price of a single equipment. The purchase price of a forklift that is most frequently used is approximately 15.000 euros. The price for a standard AGV is approximately 85.000 euros (appendix XVI);
- The residual value of a single equipment. Until, know there is no second hand market for AGVs this leads to the fact that it has no residual value. However, it does have residual value in the sense of the infrastructure and systems if new ones would be implemented. The residual value of forklift based on 60 months and 3000 hours per year is about 1000 euros. They will even be used more hours per year and could be concluded that the residual value is comparable with zero (TNT/FedEx, 2018);
- The one-time costs (for example, infrastructure changes). The one-time costs are only applicable for AGVs in this case;
- The yearly costs (think of damages etc.). The cost of damages is case specific. However, for this research these costs are assumed to be 10.000 euros per year. This price only includes the damages to the forklifts. The cost of damages, extra required hours, accidents with humans and unsatisfied customers is very hard to quantify and are considered to be additional benefit;
- Performance measures of the equipment. The performance measures of the forklift are specified within the man-hour model that is built within TNT/FedEx. The used standard times for picking up, driving 10 meters and dropping a pallet is approximately 20 seconds. For every meter after this 10 meters, it will take approximately 0,3 seconds (TNT/FedEx, 2018). The performance of the AGV is assumed to be one forklift requires two AGVs for the same job. However, the speed is divided into two measures as can be seen on the forklift. The AGV is twice as slow in driving but is three times as slow in picking up and dropping pallets. Therefore, 57 seconds and respectively 0,6 seconds are taken for the AGV. The AGV conveyor type is faster in picking and dropping the pallets and costs 24 seconds instead of 57 seconds (appendix X).

Ad 3 Outputs

The output of the model contains three parts. The first part entails the cost determination of the process of forklifts. The second part contains a full implementation of AGVs and in the third part the decision maker can chose for a combination of forklifts and AGVs.

In the first part the forklift information is given. The number of forklifts is given in the particular scenario as well as the required investment costs and the yearly average variable costs. The investment cost are the costs that initially needed for the implementation. The average yearly variable costs are the average costs taken over the lifecycle of the forklift. In appendix XVIII the format of the model is shown.

The second part consist of the output values of the full AGV implementation compared to the fully manual forklift implementation. The first row states the required amount of AGVs in this situation. This means the amount of AGVs that are required in the same situation as fully implementing manual forklifts. The investment costs are all costs which have to be made initially. The average yearly variable costs are the average costs over the life cycle. The yearly cost reduction contains the variable cost savings per year compared to the process with fully manual forklifts. The financial measures are then given. These contain the NPV, ROI and payback time. The NPV states the discounted profits over ten years compared to the case where only forklifts are used. In this NPV calculation the costs are compensated for tax and the investment costs are compensated with the forklift investment costs. The ROI gives the average yearly profit for ten years compared to the net investment costs. The net investment costs mean the investment costs compensated for tax. The payback time entails the net investment costs which are in this case the investment costs compensated for tax of AGVs minus the investment cost compensated for tax of forklifts divided by the average yearly profit. The output part could be seen in appendix XIX.

The third part contains the same information but there are two aspects which could be changed. These are the number of forklifts and the damages costs in this situation. In this part you could see the financial viability when AGVs and forklifts are implemented. The output part could be seen in appendix XIX.

4.2.2 Financial viability of the warehouse in Luik

Ad 1 Financial results

The financial viability is determined by the calculation model. The model requires different kind inputs. The important differences between the cases are the volumes, labour costs between the Netherlands and Belgium, working hours, working days, installation costs and distance travelled.

In Luik the following inputs are used:

- Volumes 105 pieces per hour and 182 in peak (TNT/FedEx, 2018)(not the real values);
- Labour costs: 15 euros (not the real value);
- Working hours: 6 (TNT/FedEx, 2018);
- Working days: 260 (TNT/FedEx, 2018);
- Installation costs: 1.000.000 euros. The installation for the AGV system is assumed to be 500.00 as mentioned in appendix XVI. The additional costs for the implementation of conveyor tables also have to be added. It is assumed that about 50 conveyor tables are required. 25 in the loading/unloading of the air side and 25 at the truck load side. This results in a table for two doors. A conveyor table is assumed to be 10.000 euros and will cost 500.000 euros for all of them;
- Distance travelled: 75 meters;
- Space requirements extra lanes. An extra lane is required in the process to separate the lanes.

In this case 12 manual forklifts are required within the shuttle process. This would require an investment of about 185.000 euros with yearly operating costs of 949.000 euros as can be seen in table 15.

Table 15 Forklift costs Luik

Results implementing manual forklifts only	
Required forklifts	12
Investment cost [euro]	€ 185.542
Average yearly variable cost over lifecycle [euro]	€ 949.533

This could also be done by 22 AGVs with investment costs of 2,9 million euros. However, the operating costs will only be 720.000 euros per year which lead to a benefit of 229.000 euros per year compared to the manual forklift case. The NPV over the 10 years will be approximately 793.00 euros. Following the NPV decision rule described in the literature review the AGV implementation is financial viable. These values can be seen in table 16.

Table 16 Results financial measures full implementation Luik

Results implementing AGVs only	
Amount of required AGVs in this situation	22
Investment costs [euro]	€2.861.500
Average yearly variable costs for operation	€720.238
Average cost reduction per year excl purchase	€229.295
Financial measures	
Net Present Value [euro]	€792.682
Non discounted Return On Investment over life cycle [%]	123%
Payback time [years]	8,8

The IRR is also very positive. The IRR is based on the discount rate (WACC). An investment is always positive for a company when a changing IRR could not make the NPV negative. As in figure 5 can be seen, the NPV will not even be negative with a WACC of 40% which is very positive.

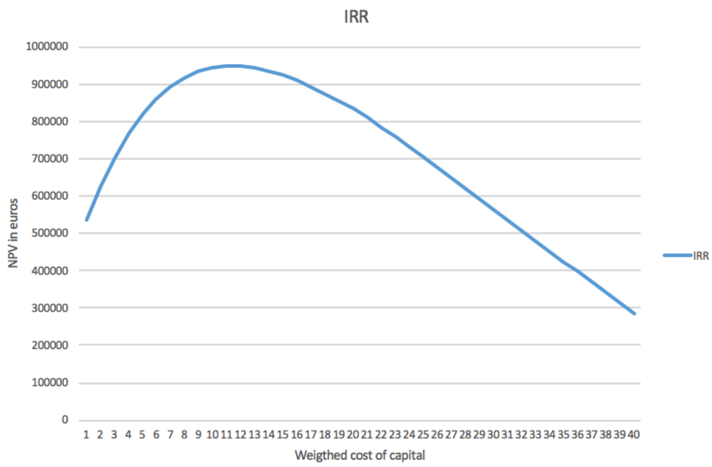

Figure 5 IRR graph Luik

Ad 2 Sensitivity results

Many of the included inputs in the model are inputs that will not vary due to circumstances (for example the pallet types). In the sensitivity analysis is measured what the impact of the different variables are on the main financial decision measure (NPV). This is done by calculating the effects of a variable on the NPV. This to determine what factors should be taken into account as important measures and to determine how volatile the results are to changes. The volatility is determined by comparing the different results in the different warehouses because in these warehouses the main impacts are changed.

Luik is a warehouse which is large and has high volumes but does this in only a couple of hours. In figure 6 the sensitivity analysis is shown. In this graph the impact of changing a factor is presented. The results show that the working days, life cycle, forklift driver costs, volumes and peak volumes have to most impact.

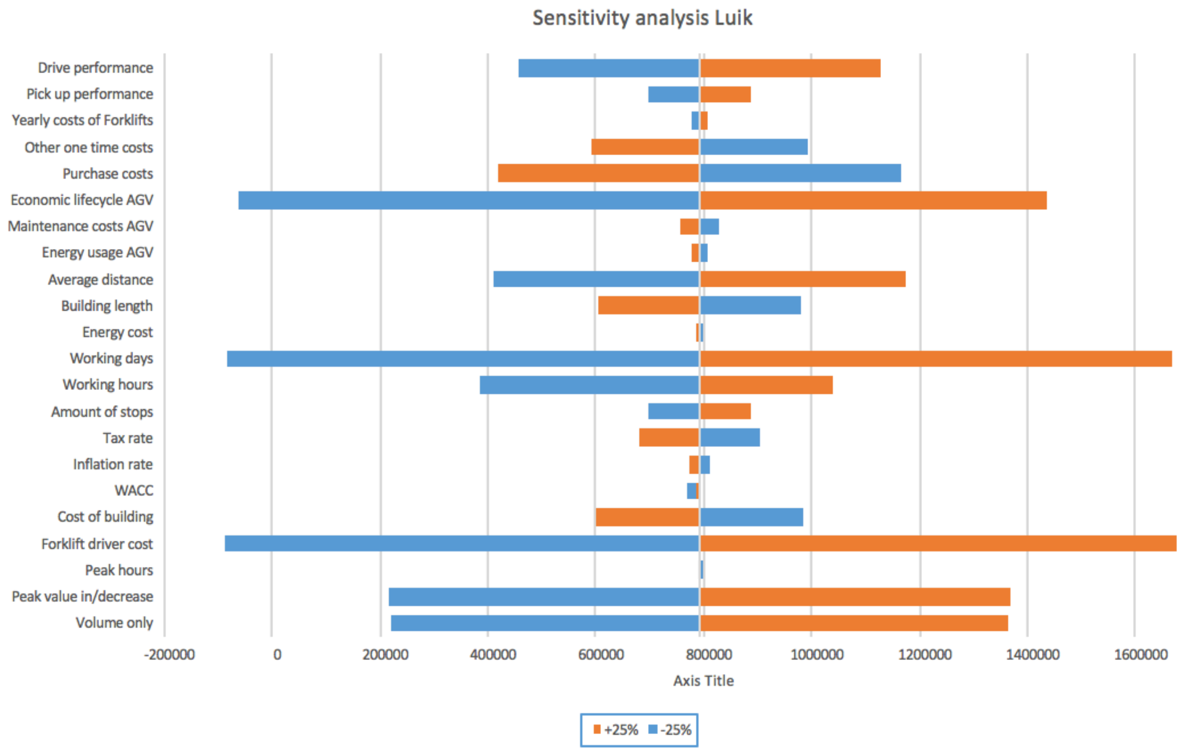

Figure 6 Sensitivity analysis Luik (calculation model 4.2.1)

4.2.3 Financial viability of the warehouse in Arnhem

Ad 1 Financial results

In Arnhem the following inputs are used:

- Volumes 57 pieces per hour and 120 in peak (TNT/FedEx, 2018)(not the real values);
- Labour costs: 10 euros (not the real value);
- Working hours: 16 (TNT/FedEx, 2018);
- Working days: 312 (TNT/FedEx, 2018);
- Installation costs: 1.000.000 euros. The installation costs of the AGV will be around 500.000 euros as mentioned in appendix XVI. Additionally, it is estimated that 50 tables are required which cost about 500.000 euros;
- Distance travelled: 50 meters;
- Space requirements extra lanes. An extra lane will be required.

In this case 5 manual forklifts are required within the shuttle process. This would require an investment of about 76.000 euros with yearly operating costs of 724.000 euros as can be seen in table 17.

Table 17 Forklift costs Arnhem

Results implementing manual forklifts only	
Required forklifts	5
Investment cost [euro]	€ 76.000
Average yearly variable cost over lifecycle [euro]	€ 723.926

In this case 9 AGVs are required with an investment of 1,78 million euros. However, the operating costs will only be 475.000 euros per year. This leads to a benefit of 249.000 euros per year and the NPV over the 10 years will be nearly 1,3 million. Following the NPV decision rule the AGV implementation is financially viable. These values can be found in table 18.

Table 18 Results financial measures full implementation Arnhem

Results implementing AGVs only	
Amount of required AGVs in this situation	9
Investment costs [euro]	€1.782.000
Average yearly variable costs for operation	€474.956
Average cost reduction per year excl purchase	€248.970
Financial measures	
Net Present Value [euro]	€1.298.838
Non discounted Return On Investment over life cycle [%]	204%
Payback time [years]	5,1

The IRR is also very positive. The IRR is based on the discount rate (WACC). An investment is always positive for a company when a changing IRR could not make the NPV negative. As in figure 7 can be seen, the NPV will not even be negative with a WACC of 40% which is very positive.

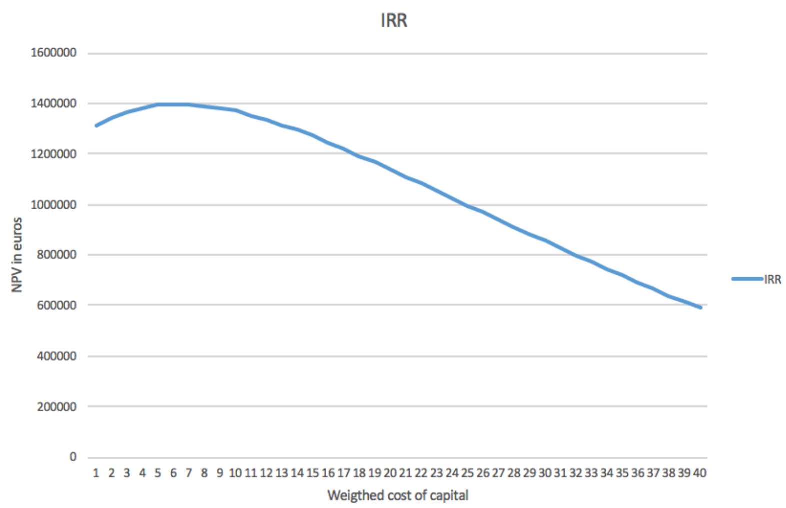

Figure 7 IRR graph Arnhem

Ad 2 Sensitivity results

Arnhem is a warehouse that processes a lot of volume during nearly the whole day. This makes the process financial attractive because the volumes over a longer time has shown to have lower peak moments, which leads to lower investment in AGVs. The most impacting factors are in this case also the forklift driver costs, workday costs, economic lifecycle and volumes and peak volume. In figure 8 the sensitivity analysis is shown.

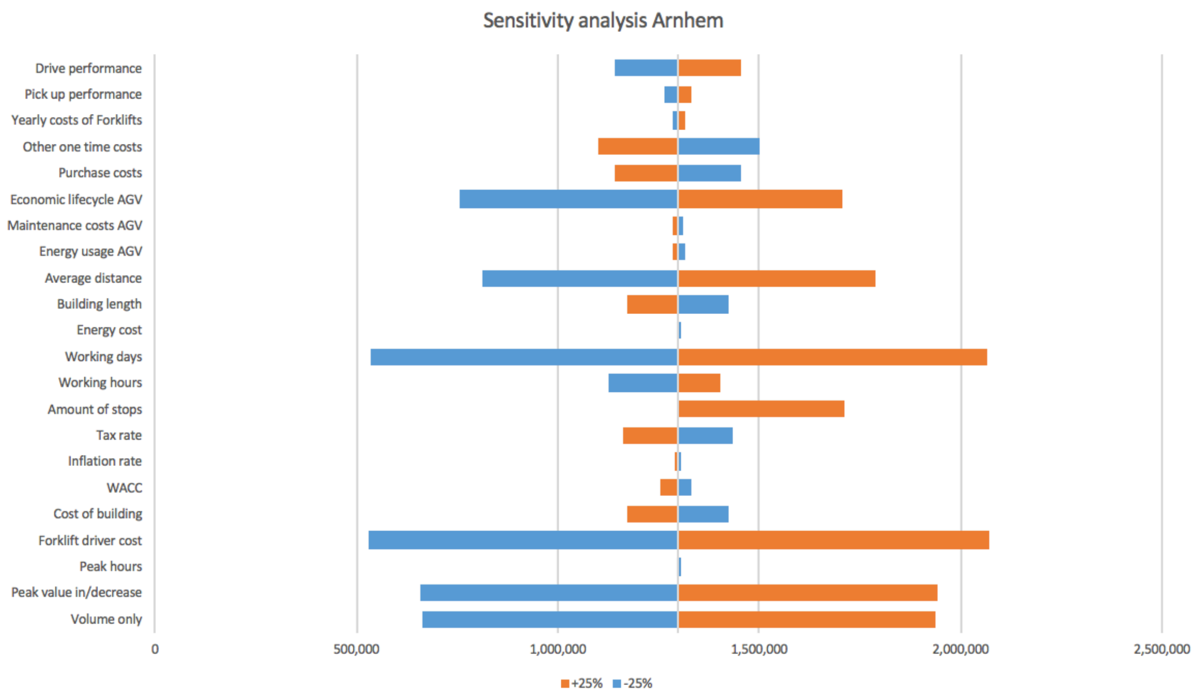

Figure 8 Sensitivity analysis Arnhem (calculation model 4.2.1)

4.2.4 Financial viability of the warehouse in Eindhoven

Ad 1 Financial results

The business case of Eindhoven is calculated when the man riders are removed from the process. This means that the value of the use of man riders has to be deducted from this business case to determine whether it is still viable. Furthermore, this business case is still very interesting to see what the profit would be at lower volumes.

In Eindhoven the following inputs are used:

- Volumes 20 pieces per hour and 40 in peak (TNT/FedEx, 2018)(not the real values);
- Labour costs: 10 euros (not the real value);
- Working hours: 16 (TNT/FedEx, 2018);
- Working days: 260 (TNT/FedEx, 2018);
- Installation costs: 400.000 euros. Installation of AGVs will cost around 250.000 euros as mentioned in appendix XVI. About 10 tables doors are required, which costs 100.000. Also, the cwcs have to be adjusted which will also cost approximately 50.000 euros;
- Distance travelled: 20 meters;
- Space requirements extra lanes. No extra lane is required. There is already a lane of 5 meters' width while there will only be one forklift and two AGVs. There is more than enough space to let them work together in this area.

In this case less than one manual forklift is required within the shuttle process. This would require an investment of approximately 15.000 euros with yearly operating costs of 166.000 euros as can bee seen in table 19.

Table 19 Forklift costs in Eindhoven

Results implementing manual forklifts only	
Required forklifts	1
Investment cost [euro]	€ 9.333

Average yearly variable cost over lifecycle [euro]	€ 166.046

In this case one AGVs is required with an investment of 479.000 euros. However, the operating costs will only be 124.000 euros per year and this reduction will lead to a benefit 42.000 euros per year and the NPV over the 10 years will be nearly 132.000 euros. Following the NPV decision rule the AGV implementation is financially viable. These values can be seen in table 20.

Table 20 Results financial measures full implementation Eindhoven

Results implementing AGVs only	
Amount of required AGVs in this situation	1
Investment costs [euro]	€479.333
Average yearly variable costs for operation	€123.911
Average cost reduction per year excl purchase	€42.135
Financial measures	
Net Present Value [euro]	€131.550
Non discounted Return On Investment over life cycle [%]	122%
Payback time [years]	8,4

The IRR is also very positive. The IRR is based on the discount rate (WACC). An investment is in many cases positive for a company when a changing IRR cannot make the NPV negative. As in figure 9 can be seen, the NPV will not even be negative with an WACC of 40%.

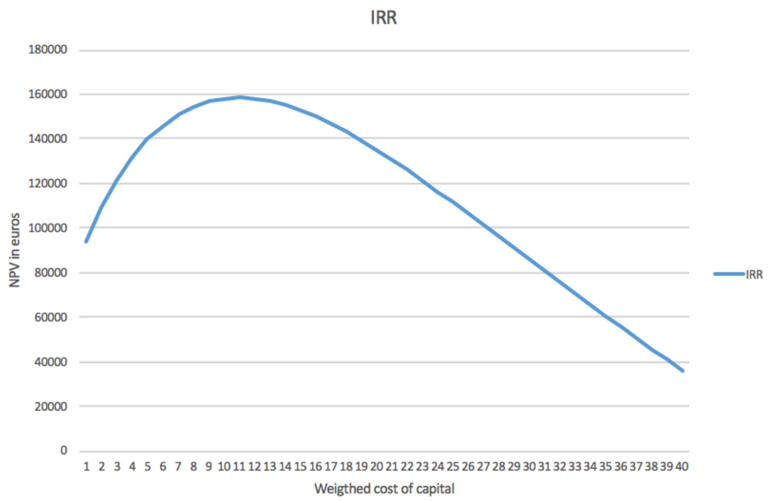

Figure 9 IRR graph Eindhoven

Ad 2 Sensitivity results

The warehouse in Eindhoven is a small warehouse compared to the other two and processes less products and is still financially attractive. In this case are the driver's costs, working days, economic lifecycle, volumes and peak volumes still the most important impacting factors. Moreover, in this case also additional measures have a large impact. These are the one times costs. The warehouses are small which means that less profit will be made and the installation costs are still high which means that this has a larger impact. In figure 10 the sensitivity analysis can be seen.

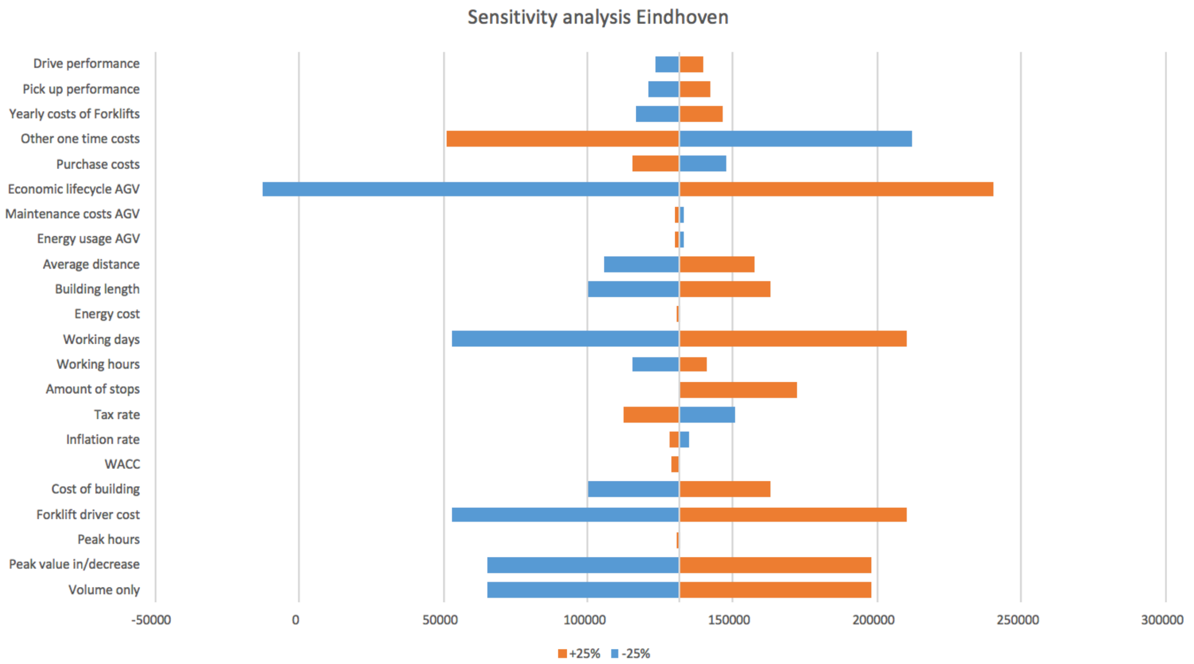

Figure 10 Sensitivity analysis Eindhoven (calculation model 4.2.1)

Ad 3 Additional benefits

Research has shown that decision-making in a manufacturing process among different alternatives depends on direct costs as well as indirect costs and benefits (Chau, 1995). The indirect/additional benefits are hard to quantify and are not taken into account due to this reason. The additional benefits will be investigated to understand which additional benefits occurred and can be quantified in future research. Multiple additional benefits were identified in literature. One of the main advantages could be to accommodate the future growth of a warehouse (Baker & Halim, 2007). Other advantages could be the availability and continuity and safer environment and with less accidents. It is orderly and cleanly, reduces stress and creates a pleasant work atmosphere. All the additional benefits apart from the financial benefits are given and explained in table 21.

Table 21 Additional benefits (Ullrich, 2015)

Position	**Description**
Scalability	The system is relative easy to scale
AGVs as mean of organization	Guidance control provides optimal material and information flow, providing more transparency
Minimizing incorrect deliveries	Automation provides for absolutely reliable transport and a high degree of process safety
Safety	AGVs works safely and with less accidents
Orderliness and cleanliness	Stress is reduced, leading to a pleasant surrounding atmosphere
Availability and continuity	AGVs work unspectacularly, without interruption, and without bustle
Ecological benefits	Lower energy use
Idea-based benefits	Positive internal and external image and technological advantage

The mentioned additional benefits were tested during the case study interviews in the warehouses. This results in a list of additional benefits within the warehouses which have to be included in AGV implementation projects. The additional benefits of AGVs identified in the literature review are the following:

- Flexibility, adaptability and scalability. Flexible in the use of space and growth of the machines;
  - Within 5-10 years the growth will higher and it is hard to find forklift drivers already. So, it is necessary to look more sustainable and scalable solutions to keep to processes flexible and reliable. This is important because TNT already has serious problems with customers because of missed deliveries. See appendix XXVII;
- AGVs as mean of organization. AGVs ensure transparency due to the guidance control of the flows;
  - One big inefficiency is that the forklifts transport the pallets to the destination but they come back empty, so the way back is just waste. See appendix XXIII;
  - Another advantage of AGVs is the possibility to store pallets in particular areas because they have no priority. A first in first out system is in many cases not applied. With AGVs a Just in Time system could be applied which means that when a truck is to late that they could give this truck priority. See appendix XXVII;
  - The most excessive costs in the current process seem to be the drivers distance. There is not much of a planning or efficient way how they should take the pallets to the destination. See appendix XXII;
  - Advantages are more planning capabilities. See appendix XXVIII;
  - Another inefficient part of the forklifts is that they drive with a pallet and come back without anything on the forks. See appendix (XXII, XXIX);
  - The pallets are not prioritized. See appendix XXVI.;
- Minimizing incorrect deliveries. Automation provides a high degree of process safety;
- Safety. AGVs work accurate and less accidents;
  - The company has to pay for damages done by forklifts. See appendix XXVII;
  - Damages happen and not always because of the forklift driver but also due to the bad pallet quality. An advantage is less damages. See appendix XXX;
- Orderliness and cleanliness. The process will be more peaceful which makes the environment more pleasant;
  - It is believed that the process will be more peaceful and safe. See appendix XXIX;
- Availability and continuity. AGVS work without breaks and interruptions;
  - A big advantage is that you do not have to take care anymore with the flu waves and the employee supply shortage. See appendix XXIIII;
- Ecological benefits. Lower energy;
- Idea-based benefits. Positive internal and external image, technical advantages.

The most frequent mentioned additional benefits are the increasing transparency and being able to prioritize pallets and increased safety. The flexibility and scalability, orderliness and cleanliness and availability and continuity are also mentioned by the managers. Scalability and availability and continuity could also have a large impact on the benefits. There was nothing mentioned by anyone about incorrect deliveries, ecological benefits or image benefits and these factors are therefore assumed to be not important.

4.2.5 Financial viability analysis

Ad 1 Financial results

In this financial calculation the non-conveyor transport process is analysed by comparing the costs and benefits of the AGV with those of the forklifts that are currently used. This means that the NPV for example is given compared to the forklift meaning that if the choice has to be made between the two technologies the NPV tells you whether it is better to implement AGVs or not. The calculations were done in a model which make it possible to change al the values for every warehouse in the future to determine the expected viability.

The inputs of the different warehouses are mentioned in table 22. The difference between the warehouses is mainly the amount of volumes and between Luik and Arnhem/Eindhoven the working hours. In Luik they have nearly as much volumes as in Arnhem. The difference is that in Luik they process these volumes in six hours and in Arnhem in sixteen hours. This makes the process in Luik less efficient because more equipment and space is required. This is also the reason why the NPV is much higher in Arnhem than in Luik while the hour wages are even lower. The working days in Arnhem are also higher which leads to higher profits. Eindhoven is very small compared to the other locations and is still making profit. While, the return on investment is lower and the payback time higher for Eindhoven. This due to the fact that the installation costs are in percentage terms very high compared to Arnhem. Another difference is the drive way in the Eindhoven warehouse is assumed that AGVs and forklifts can work together because there will only be one forklift and one AGV in this process for a lane of 5 meters which is very much. In the other warehouses is assumed that an extra lane has to be implemented for driving with load and the way back is assumed to be possible at the same lane. The extension of the lanes does reduce the NPV significantly, but the extra lane does extend the capacity of the space and is more sustainable for future growth. Furthermore, there are no limitations included in this part of the process and this has to be further investigated later on.

Table 22 Input values warehouses

Inputs	Luik	Arnhem	Eindhoven
Volumes and peaks (not the real values)	105 and 182 in peak	57 and 120 in peak	20 and 40 in peak
Labour cost (not the real values)	15	10	10
working hours and days	6 hours 260 days	16 hours 312 days	16 hours 260 days
Installation costs	1.000.000	1.000.000	400.000
Distance travelled	150	100	20
Extra drive lane	Extra single lane	Extra single lane	Non

All the cases were financially attractive as indicated by NPV decision rule and IRR as can be seen in table 23. The results in NPV differ much per warehouse. This is because differences in inputs, the volumes and peaks, working hours, forklift driver costs and working days had a lot of impact as pointed out by the sensitivity analysis. The payback time is between the five to eight years for the different warehouses. This is quite long for an investment. The ROI differs from 120 to 210%, meaning that the investment efficiency can differ approximately by 90%.

The found additional benefits are the increasing transparency and being able to prioritize pallets, increased safety, the flexibility and scalability, orderliness and cleanliness, availability and continuity. Nobody mentioned that incorrect deliveries, ecological benefits or image benefits as additional benefit. The increased transparency could have large impacts on the business case because this could result in a very efficient planning and could lead to fewer missed deliveries. Increased safety could also lead to savings because until now only damage to the forklifts are included in the business case. Scalability and continuity could also increase the benefits because the technology is future-proof and does not need any breaks and does not get ill. This is neither included in the business case yet. The business case based on the NPV is already positive while it could even be more positive including these factors.

Table 23 Financial results

Financial results	Luik	Arnhem	Eindhoven

NPV [euros]	800.000	1,8 million	130.000
IRR [%]	40+	40+	40+
Non discounted ROI [%[]	123	204	122
Payback time [years]	8,8	5,1	8,4

Ad 2 Sensitivity results

In the sensitivity analysis the robustness of the financial calculations will be determined. This sensitivity analysis will also identify the impacting factors. In this research is the NPV of the three warehouses is positive. The four largest impacting factors were similar in the three warehouses, which means that it is likely that these factors are important in different warehouses as well. The difference in warehouses is concerning the volumes, driver costs, working hours, working days and installation costs. These factors are also the most common impacting factors, which means that the three warehouses already show that the results are not sensitive to changes. The found common factors were: forklift driver costs, life cycle, working days, volumes and peak volume. Only Eindhoven has one additional impacting factor which is the one time costs as can be seen in table 24. This is logical because the volumes are quite low in Eindhoven and still a large part of the one-time investment costs have to be paid which make the investment less attractive. All the possible variables are tested within the three warehouses, to see what happens when one of the variables were changed by 25%. Changing these variables did not make the NPV negative.

Table 24 Impacting factors

Important impacting factors	Luik	Arnhem	Eindhoven
	Forklift driver costs	Forklift driver costs	Lifecycle
	Working days	Working days	One time cost
	Lifecycle	Volume	Forklift driver costs
	Volume	Peak volume	Working days
	Peak volume	Lifecycle	Volume
	-	-	Peak volume

To conclude, in the three warehouses it is found that the most impacting factors were the driver costs, life cycle time, working days, volumes and peak volumes. Furthermore, the differences between the warehouses analysed are the same variables excluding the life cycle. This means that the results are not sensitive enough to change the financial viability. These factors were also found as the factors with the most impact in the single sensitivity test in the warehouses. The factors mentioned are however interesting to select warehouses for further implementation research. It should be noted that these factors have the highest impact but can change in every case and must always be checked.

4.3 Regulatory viability

4.3.1 Results manufacturers

The regulatory viability is important because any regulations which block the implementation makes the AGV unviable. The manufacturers did not mention any problems regarding the regulatory environment. There are some safety specifications but these are mainly on safety margins as described in appendix (VII, VIII, IX, X)

4.3.2 Regulatory viability of the warehouse in Luik

The question concerning regulations was only asked and mentioned by the health and safety manager: "There are no specific regulations for co-operation between AGVs and manual forklifts. However, it is preferable to divide humans and machine because he has experience with problems between them." This means that the regulatory environment will not be a problem. The interviews can be found in appendix (XXI, XXII, XXIII).

4.3.3 Regulatory viability of the warehouse in Arnhem

Both of the experts do not think that the implementation of AGVs will be a problem with regard to regulations. Such an implementation has to take into account the health and safety requirements, but these are not expected to be a problem within the opinion of the health and safety expert. "I would not expect many problems concerning regulations because there are multiple examples in warehouses where AGVs are used". There is not even a law for the speed of forklifts within warehouses. The employee association only give an advice speed which is only six km/h while the forklifts are driven eight km/h and in the past even ten km/h". This means that the regulations will not be a limiting factor. The interviews can be found in appendix (XXIV, XXV).

4.3.4 Regulatory viability of the warehouse in Eindhoven

In this Eindhoven the team leader had not enough knowledge to judge if regulatory aspect would block the implementation of AGVs. The interviews can be found in appendix (XXVI).

4.3.5 Regulatory viability analysis

The case study identified that the regulations allow an AGV implementation. In the warehouses the interviewees did not mention any problems concerning regulations. However, one of the Health and Safety managers said that it is recommended to separate machine from the manual forklifts to decrease the chance of problems concerning the collaboration. Literature also verified that machines and humans could work together but that the humans have to be well willing (Ullrich, 2015). Eventually, the manufactures did not experience regulations as limitation.

The manufacturers were not mentioning any problems with the regulatory environment. There are some safety specifications, but these are mainly on safety margins.

4.4 SOCIAL ENVIRONMENT VIABILITY

4.4.1 Social environment viability of the warehouse in Luik

Planning and Engineering manager & trade-union chairman: "The social aspects of these kind of machines. Each time the machine will help the human it will be seen as an advantages to the unions. For example, if it helps to lift a product instead of lifting the product manually it will be seen as an advantage. When the goal is to reduce staff you could expect a hard discussion and it will be likely that you have to come up with really good arguments and a plan what you will do with the employees. Time to time it is more beneficial to close the facility and open a new one than maintaining 75% of the crew." The two operation process engineers said the following (industrial engineers): "The trade unions will interfere with this implementation. There must be good reasons for implementation and a plan must be there concerning the employment for the employees." Eventually, the Health and safety manager: "The trade unions will not like the AGV implementation on the health & safety part. When you would like to implement AGVs you have to come up with a plan about what it will improve regarding safety for the workers. AGV implementation should be more useful for new warehouses because then you can design the warehouse the way you want and you have less resistance from the unions."

4.4.2 Social environment viability of the warehouse in Arnhem

Both of the experts do not expect any problems with the trade unions. H&S manager: "In the Netherlands you will not have much problems with trade unions. In Germany, for example, this could be a problem". The transition operational manager said: Without job losses you will not have any problems with unions. However, if you are going to fire people you will have to come up with a social plan and the higher management has to negotiate on this matter. If the unions are not agreeable on this matter, they can go to the justice officer and if he decides based on the company’s arguments that they could fire their employees otherwise they could not. A company is free to do this if it has many advantages for them (for example to remain competitive). This means that the introduction of AGV will not be a problem within the warehouses of the Netherlands. However, it could cost money to fire people in the same warehouse. Therefore, it could be useful to open a new warehouse.

4.4.3 Social environment viability of the warehouse in Eindhoven

The interviewee in Eindhoven said the following: "Not very familiar with the unions. But, when I am going to change the working conditions and amount of employees, I need to come up with a plan. I think this will not be a problem that will limit the implementation."

4.4.4 Social environment viability analysis

All of the interviewees mentioned that the unions will not necessarily be a problem. However, there must be a good reason to fire employees for such a technology. The findings are different between the Netherlands and Belgium. In the Netherlands the unions are less strict. If you would like to fire employees for a technology it could be acceptable. In Belgium you could expect hard discussions when it is not helping the employees (increased safety for example). In both countries they recommend to applying such a technology in a new warehouse or implement it slowly, so that the employees will not be fired. Manufacturers did not mention social environment as limitation explicitly. So, it is social viable but compliance with the labour contract is required when people will get fired.

4.5 Overall analysis of the results

Initial research was performed to identify which process should be investigated. The non-conveyor process was chosen, because the process is dangerous, labour intensive and TNT/FedEx was therefore most interested in this process. The non-conveyor process consists of three parts; (un)loading, transporting and (un)loading pallets through the warehouses into the trucks. In the early stage of the research was found that loading and unloading could not be done by AGVs yet because this would take too much time and is technically impossible with the number of different pallets. The transport part of the non-conveyor process could still be investigated.

The forklift AGV and the conveyor AGV were identified as possible AGV applications for express delivery companies. The technical viability is determined by identifying the most important requirements and limitations in general by manufacturers. These limiting requirements are tested in the warehouses by observation and by interviewing the warehouse process experts. The main limitations found were the lack of predefined pallets, predefined pallet storage areas and limited space. The limited space could be resolved by building a new building or expanding the building.

The process could not be fully automated by AGVs because the used pallets within TNT are not standardized. The percentage that could be automated is higher for AGV conveyors than for AGV forklifts. The AGV forklift can only pick up predefined pallets and the load on the pallet must be within certain dimensions. The AGV conveyor does not require predefined pallets but the dimensions of the pallet have to be within the dimension of the conveyor itself.

The predefined location of the pallets is limited because for the AGV forklift the pallets have to be in a particular place with a placement range of a number of centimetres. Furthermore, the buffer area is in the loading side where the AGVs could not drive because they will block the loader or unloader. This could be solved by implementing conveyor tables at the loading side, which transfers the pallets to the pickup place for the AGV. The use of an AGV conveyor makes the AGV forklift unnecessary because the AGV conveyor has higher performance and could handle many more pallet types. The conveyor AGV is technically viable when the conveyor table is implemented and if there is enough space available for usage. Furthermore, the conveyor type is still not able to handle all pallet types. In the larger warehouses it is recommended to separate the manual forklifts and AGVs but must be determined per warehouse because the success of collaboration between manual forklift and AGVs is depended on the willingness of the manual forklift drivers. One of the technical differences between the warehouses types was that in the station of Eindhoven the volumes were not transported from buffer to buffer but from the buffer tot the cwc to the buffer. This results in the fact that only the part from cwc to buffer could be automated and the cwc must be adjusted to the conveyor height which results in another limitation. Man riders are used in the warehouse of Eindhoven and these riders cannot lift pallets to such heights. The financial analysis should be compensated for the change from man riders to forklifts in this process.

Financial viability literature was reviewed and found that the NPV and IRR is mostly used to evaluate investment projects. The NPV and IRR are calculated for the conveyor AGV in the three different warehouses. These calculations were executed with the characteristics of the current warehouses, taken into account the cost for the additional space and conveyor tables. The NPV and IRR were positive for the three analysed, warehouses, which are the decision criteria to determine whether the investment is viable. There are differences in results between the different warehouses which could be explained by the sensitivity analysis. The sensitivity analysis found the following impacting factors: forklift driver costs, volume, peak volumes, working days and lifecycle. These factors were found in the three warehouses as the most impacting factors. Eindhoven only had an additional factor which was the one times costs. This is due to the fact that the investment costs were high compared to the volumes. The impacting factors were also the varying input values of the warehouses which means that the impacting factors seem to be representative for the warehouses in general and also make the calculations more robust and reliable. The warehouse in Arnhem for example has the highest volumes per day and working days which lead to the highest benefits compared to the other warehouses. The warehouse in Luik also has a lower NPV since that the working hours per day with nearly the same daily volumes is six hours instead of sixteen hours meaning that more AGV are required which are expensive and reduces the NPV. Furthermore, the impacting factors can be used to determine in what kind of warehouses this technology must be implemented to achieve the highest NPV. Not only the main impacting factors have to be considered because the lower impact values could also have large impact. Because the sensitivity analysis shows the changes of every factor by -25% and +25% while the working hours could vary more than 200% as well as the distance could differ much in different warehouses which would result in a large change. The warehouses in different countries for example, could have large differences in labour costs as found between the warehouses in the Netherlands and Belgium. Additional benefits were not even considered in these calculations while they could increase the financial viability. The benefits identified are: increased safety, plan ability, scalability, availability & continuity and a more orderliness & clean process. One of the examples that could cost a lot of money is missed delivery times because of labour shortage.

The regulatory environment is viable. There are only a number of safety margins rules but these are not limiting the implementation of AGVs. The collaboration between AGVs and humans is even allowed. The social environment is viable too. However, every country has their own trade unions. In Belgium it is hard to replace humans by robots if it does not help the humans. In the Netherlands for example it will be easier to fire people for a process optimization. In both countries a social plan must be written or AGVs must be implemented in a new warehouse. In both countries the interviewees advised implementation in a new warehouse to reduce resistance. The social environmental viability must be determined case specific. A new warehouse is technically required but also preferred on the social aspect.

5 DISCUSSION

In this chapter will be described what can be learned from this research and what should be further investigated. In the first part will be explained what the results are. The second part will elaborate on the different assumptions made and the used research model limitations. The third part will provide recommendations for future research.

5.1 INTERPRETATION

The non-conveyor process consists of three parts, the loading, transporting and unloading part (or the other way around). In this process, in which pallets are handled by forklifts it is impossible to load or unload the trucks by AGVs. This is due to the time limitations and is expected to apply for every express delivery company. One of the characteristics of express delivery companies is handling packages as fast as possible, so loading/unloading of trucks has to be done as fast as possible. However, apart from the technical challenges, AGVs are slower compared to the manual forklifts. It is not possible to just use more AGVs to load or unload trucks because the trucks have particular dimensions. The implementation of the AGV conveyor seems to be viable for all the three investigated warehouses in the transport part of the non-conveyor process. The following conditions have to be met to implement the AGVs; the building will need to be expanded and conveyor tables will need to be implemented. The question is whether this applies to express delivery companies in general. The technical limitations found in the different warehouses were nearly similar to each other. This could be because the buffer to buffer (transport) process is quite a straight forward process and is not expected to be very different in other warehouses. TNT is expected to have similar processes as other express delivery companies. Difference in packages types could exist but is not expected to be less standardized than within TNT, so this will not have significant impact on the results. Increased standardization will only lead to higher financial benefits because the process will still be executed in the same way. The social and regulatory viability will not differ per company but per country, and thus will have to be determined per country specifically. The financial viability is determined in the three warehouses, which have different input variables and in all of them they are financially viable. The variables are therefore expected to be viable in other warehouses as well. However, the impacting factors on the financial results are identified and for example labour costs have a huge impact on the financial viability. It is known that the labour costs could differ much in different countries, which could lead to different financial outcomes in different countries. This makes it necessary to recalculate the financial results in every case or to obtain more case studies on the differences. The calculation model and impacting factors identified in this research could therefore be used if the analysed cases have a buffer to buffer process. Until now, there is not yet a proof of concept of the technology itself in express delivery companies, which means that this should be obtained first to secure that the AGVs are working in the warehouses. Neither is a design study performed to determine whether there are more efficient ways of implementing these AGVs. This would make the AGVs more viable. If the proof of concept and design study are done, every warehouses could be evaluated on the financial, social and regulatory factors to determine the real viability in the warehouses. The strength of AGVs lies in general in operating in standardized and continuous process. This research found that it is also financial attractive in processes where not the complete flow can be automated and where the process is not running 24 hours a day. Furthermore, the identified technical limitations are the ones which are also expected to be most common in other industries and could be used to identify the viability in other industries. The regulatory and social environmental factors are determined for the Netherlands and Belgium, which will also apply for other industries. Moreover, the financial viability is calculated in the transport process which could apply to multiple industries where pallets will be transported from a to b. This research gives insight in the limitations and benefits of AGVs in transporting pallets compared to transporting them with manual forklifts. Furthermore, it was found that the buffer to buffer process takes place in the relatively large warehouses.

5.2 MODEL LIMITATIONS/ASSUMPTIONS

In the research the choice was made to perform a case study at three warehouses of TNT. One of the limitations of this case study is that only three warehouses were investigated in two different countries due to time and resources limitations. This can make the results less generalizable because the identified variables to determine the viability could be very different in other countries. Fortunately, the different impacting variables were identified in this research and could be easily verified for the evaluation of warehouses in other countries. The viability is determined based on a new developed model since there are no dominant evaluation models and the most prominent ones used within companies are only assessing financial aspects. Only assessing financial aspects is considered insufficient to properly determine the viability. However, the used factors could still be unsatisfying for the objectives of every company. Future vision for example could be included to give a better estimation for the objectives and viability of AGVs for the company in the future. The chosen warehouses are also owned by one company, which decreases the generalizability of the research, but it is still expected that the other express companies have the same processes. If they have a non-conveyor process with a buffer to buffer process it will definitely apply to them, and the viability results are expected to be more efficient because TNT is expected to accept more types of pallets than other express delivery companies. Eventually, in this research no proof of concept is considered, which decreases the technical limitation part because it is not shown to be working yet.

Multiple assumptions are made within the determination of the viability and the most important assumptions must be taken into account as possible limitations. In the research is found that the warehouses are too small for an AGV implementation. This could be different in other warehouses and should be incorporated in future research and is also one of the reasons why every warehouse has to be re-evaluated. It is also assumed that the drive way is not used as buffer area, which could be different in other warehouses. Another assumption is that the AGV and manual forklift have the same performance as in the stand alone concept. A difference in this assumption will not directly lead to the unviability of AGVs. It is assumed that loader/unloader is capable of putting the pallets on the conveyor table and will not reduce its performance significantly. The extra space required for AGVs is determined based on the used drive way rule within TNT and could differ from other warehouses of other companies. It is also assumed that the performance of the manual forklifts is equal in the different warehouses, whereas this could be different; depending on the rules within the warehouse. The warehouses have labelled pallets which could be scanned to determine the required destination of the pallet within the warehouses which could be different in warehouses of other companies. The additional benefits were not incorporated in the financial analysis while this could improve the business case and must be evaluated case specifically. Furthermore, it is assumed that only 50% of the pallets could be handled by the conveyor AGV; this could differ at other warehouses. As mentioned in the model limitations it only includes the current state and the future of the technology and the warehouses could also impact the business case. Internet of things is for example growing which makes automation more desired. Only damages to trucks are incorporated in the research and not the social costs of harming employees. Another important assumption is that the employees for the peak moments are paid during the whole working day. In many cases it is unknown when the peak moments will arise. Therefore, employees will be hired the whole day due to the labour contracts.

5.3 FUTURE RESEARCH

The future research recommendations are divided in recommendations for express delivery companies and for the academic literature. This separation is made because express delivery companies are interested in the next steps for implementation while academic literature is more interested in the viability of AGVs in express delivery companies in general and the lessons learnt for other industries.

5.3.1 Future research for express delivery companies

The results have shown that an AGV implementation will be viable for use under certain conditions. These general results make it useful to perform more research to the implementation of AGVs. Until now there is not yet a layout design for the use of AGVs different from the current situation and this must be researched. Another important aspect is obtaining a proof of concept of the AGVs in the warehouses to see whether the technology does function in the warehouses and to verify the assumptions made in the research. If this is done successfully warehouses could be chosen based on the impacting factors to automate a warehouse that is most viable. Also, the technical, regulatory, social environmental factors, additional benefits and future developments have to be incorporated.

5.3.2 Future research for academics

The academic point of view includes more recommendations for further research because it is important to obtain more generalizable knowledge. To obtain more generalizable results it is recommended to perform more research on the following subjects:

- The process differences between the analysed warehouses versus those of other companies should be mapped to understand whether every express delivery company has a non-conveyor process with a buffer to buffer part and to say more about the results in general;
- The different input variables in different countries; this way something could be said about the financial viability in different countries;
- The social and regulatory environment for the different countries to be able to determine whether these aspects are not a problem in other countries;
- How AGV conveyors could be optimally used within the transport process in the warehouses;
- How the additional benefits could be quantified and how much influence the future developments will have on these benefits and the viability.

6 CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research was to determine how viable AGVs are for implementation in warehouses of express delivery companies. The research found that a specific AGV application could be viable for implementation in the non-conveyor process in the warehouses under certain conditions.

In the early stage of the research was found that the loading and unloading of trucks could not be done by AGVs yet. This is due to the technical challenges and the AGVs are way too slow. The technical analysis has shown that current warehouses are too small to implement AGVs. Therefore, the building must be expanded or a new one must be built. Furthermore, conveyor tables are required to separate the (un)loading side from the AGV operations and to comply with the requirement that pallets must be placed on predefined areas. The required implementation of conveyor tables makes the AGV conveyor more viable than the forklift AGVs due to the higher performance and load capacity. The financial analysis based on the NPV and IRR has shown that the implementation of the AGV conveyor is positive. This calculation included the costs of the required extra space and conveyor tables. Moreover, the sensitivity analysis found that the input factors of the evaluated warehouses were also the impacting values in general. This means that the results are reliable and robust for the analysed warehouses. The regulatory environment will not be a problem, there are safety margins which have to be incorporated, but these will not be limiting. The social environment is viable. However, every country has their own trade unions and a social plan must be written that includes what will happen with the employees when they will be fired. The AGV conveyor is viable for use in expanded or new warehouse with conveyor tables. Moreover, multiple input values are case specific and it is recommended to perform a viability study for every implementation project.

The discussion found that the results are not necessarily generalizable for all express delivery companies. One of the findings was that the AGV are most viable in standardized and continuous process. This research found that it could also be financially attractive in processes where not the complete flow could be automated and where the process is not running 24 hours a day. Furthermore, the identified technical limitations are the ones which are also expected to be most common in other industries and could be used to identify the viability in other industries. The regulatory and social environmental factors are determined for the Netherlands and Belgium, which will also apply for other industries. Moreover, the financial viability is calculated in the transport process which could apply to multiple industries where pallets will be transported from a to b. This research gives a lot of insight in the limitations and benefits of AGVs in transporting pallets compared to transporting them with manual forklifts. Another finding is that the buffer to buffer process takes place in the relative large warehouses. TNT is expected to have similar processes as other express delivery companies while the difference in packages types could exist but is not expected to be less standardized then TNT which then will not have a significant impact on the results. Moreover, the location of the warehouses could change the financial results since the impacting factors are different. The social and regulatory viability will not differ between the different companies but between different countries and have to be determined per country where AGVs will be implemented. The financial viability is determined in the three warehouses which have different input variables and in all of them they are financially viable. Thus it is expected that the results count for multiple warehouses. Until now there is not yet a layout design for the use of AGVs different from the current situation and this must be researched. Another important aspect is obtaining a proof of concept of the AGVs in the warehouses, to see whether the technology does function in the warehouses and to verify the assumptions made in the research. If this is done successfully warehouses could be chosen based on the impacting factors to automate a warehouse that is most viable. Also, the technical, regulatory, social environmental factors, and additional benefits have to be incorporated. The academic recommendations are different because generalizability is more desired in the academic environment. As mentioned earlier the warehouses results are depending on different input variables which are dependent on the different countries. To obtain more generalizable results more research should be performed on the differing variable between the different warehouses and in different countries as well as how the layout could be optimized and how additional benefits could be quantified as mentioned in the discussion.

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Appendix I INTERVIEWS WITH MANUFACTURES

Job title:

Company:

Context

I am conducting research at TNT/FedEx as graduate from the Master Management of Technology at the TU Delft in the Netherlands. The research objective is reducing the uncertainties for express delivery companies concerning the capabilities, limitations and suitability of implementing Automated Guided Vehicles (AGVs) in their distribution centers.

The research will be performed for the forklift process in the distribution centers. Express delivery companies are chosen because these processes are hard to automate due to the different volumes and dimensions. During my research I found that the AGV technology is not yet developed sufficient enough to load and unload trucks. However, AGVs may could be used in the "transport" phase between loading and unloading. Therefore, I would like to obtain knowledge about the AGV forklift solutions.

The obtained knowledge will only be used to determine the suitability and current limitations of the AGV solutions for delivery express companies. Some of the questions are possibly hard to quantify, for these questions I would like to ask you to give a more general answer.

Part 1:

General

- What do you think of loading and unloading of pallets with AGVs?

- What are the main advantages or disadvantages of AGV forklifts?

- Are there any other significant differences between manual forklifts and AGV forklifts?

- What are the requirements for implementation?

- Is there anything else what you would like to mention?

Technical viability

- What are the main requirements for implementation of AGVs?

- What are the limitations for implementing AGVs in the 'transport' process in warehouses of delivery transport companies? (what would make the implementation impossible?)

Regulatory viability

- Are there any regulations or limiting regulations concerning the use of AGVs?

Part 2: Costs and performance

Performance

- How much space is required for operating AGV forklifts? (for example, how many AGVs can operate at the same time in 10 square meters)

- What is the performance difference of AGVs comparing to the average manual forklift (for example, the AGV is x times slower/faster then the current forklifts in performing the same job?)

- What is the performance difference in energy use between manual forklifts and AGVs?

- Are there any other important performance differences between manual forklifts and AGVs?

- What is the economical life time of AGVs? Does it differ significantly from manual forklifts?

- Are there cases where they are already used in non-standard processes?

- Could the same forks/chargers of the manual forklifts be used for AGVs?

Costs

- What is the difference in price for the purchase of AGVs compared to manual forklifts? (For example, two times more expensive?)

- What are differences in operating costs between manual forklifts and AGV forklifts?

- What are differences in maintenance costs between manual forklifts and AGVs?

- Are there any special costs and what are they approximately? (thinking of placement costs, start up costs, employment, extra spare parts, etc.)

- Are there any other important cost differences between manual forklifts and AGVs?

- Can the maintenance costs in general be assumed to be linear with the use of the forklift/AGV?

- What is the residual value of forklifts/AGVs?

Appendix II INTERVIEW IN THE WAREHOUSES

Job title:

Warehouse:

Context

I am conducting research at TNT/FedEx as graduate from the Master Management of Technology at the TU Delft in the Netherlands. The research objective is reducing the uncertainties for express delivery companies concerning the capabilities, limitations and suitability of implementing Automated Guided Vehicles (AGVs) in their distribution centers.

The research will be performed for the forklift process in the distribution centers. Express delivery companies are chosen because these processes are hard to automate due to the different volumes and dimensions. During my research I found that the AGV technology is not yet developed sufficient enough to load and unload trucks. However, AGVs may could be used in the "transport" phase between loading and unloading. Therefore, I would like to obtain knowledge about the AGV forklift solutions.

The obtained knowledge will only be used to determine the suitability and current limitations of the AGV solutions for delivery express companies. Some of the questions are possibly hard to quantify, for these questions I would like to ask you to give a more general answer.

Part 1:

AGV

What do you think about AGVs?

What would be the reason to implement them?

What do you think that possible limitations could be for implementing AGVs?

What do you think a AGV could not do? and why not?

Regulations

Are there regulations that could block the implementation of AGVs within the warehouse?

Are there any other important regulatory aspects to take into account while implementing AGVs?

Socio cultural aspects

Will there be any problems with trade unions when you implement AGVs?

What would happen with the employees?

General

Could you give me an explanation of what you think is important for implementing AGVs, or not?

Any other things you want to add concerning my research?

Part 2:

Current process

What do you think of the current forklift process?

What do you think that are important costs in the current process?

What are current problems in the forklift process?

What percentage of the non-conveyable are not on standard pallets?

What are the costs in the current process by damages, connecting times etc?

Appendix III INTERVIEW ENGINEERING DEPARTMENT

Job title:

Company:

Part 1:

AGV

- What do you think about AGVs?

- What are possible limitations of AGVs in the process?
    - Different throughputs
    - Different times

Part 2:

Current process

- What do you think of the current forklift process?

- What do you think that are important costs in the current process?

- What are current problems in the forklift process?

- What are the costs in the current process of damages, missed connecting times etc?

Appendix IV EXAMPLE DATA ANALYSIS

The data analysis is done in two parts. The first part determines the problems and their significance and the second part determine whether enough interviews were conducted. In this paragraph an example will be given for interviews with the manufactures.

The limitations that were found by the interviews are written down per manufacturer and are shown schematically in table 25. In the result side every limitation is shown and how many times they were called by the manufacturers. This could say something about the significance of the problem. Furthermore, the significance of the problem could be determined by evaluating the limitation itself.

Table 25 Limitation oversight

Interviews Technical viability manufactures	Manufacture Jungheinrich Execution date: 03-02-2018	Manufacture Execution date: 06-02-2018	Manufacture 3 Execution date: 08-02-2018	Manufacture 4 Execution date: 10-02-2018	Results
	- Aisle width	- Aisle width - Pallet quality -Traffic problems	- Aisle width - Pallet quality	- Traffic problems	- Aisle width (3x) - Traffic problems (2x) - Pallet quality (2x)

The second step is determining whether the amount of interviews was sufficient. In figure 11 could be seen that in the first interview one new limitations was mentioned and in the second two. However, in the third and fourth no new limitations were mentioned anymore. This means that enough interviews were conducted.

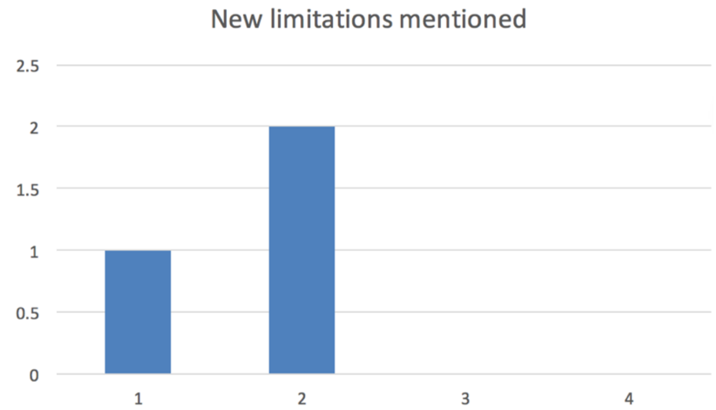


Figure 11 New limitations mentioned over time

Appendix V AGV APPLICATIONS

Two kind of AGV types are there for express delivery companies and will be described below.

Conveyor/piggyback AGV

These AGVs are different from the forklift AGVs in the sense that they do not have forks anymore as can be seen in figure 12. This AGV has a conveyor which makes it easier to transport different kind of products. One of the disadvantage of the conveyor AGV is that it cannot lift the products and requires a certain height to pick the products because it requires a pickup conveyor. The AGV conveyor can be bought in different types where the conveyor has one, two or one big conveyor (Dematic, 2018) (Ullrich, 2015).

Figure 12 AGV conveyor (Dematic, 2018)

Standard forklift AGV

The standard AGV forklift is comparable with the current used manual forklifts. The difference between them is just and only that the automated version has sensors which make the forklift able to drive automatically. One of the advantages is that the AGV could pick pallets from the ground and is able to lift the products. One of the disadvantages is that every pallet has to be predefined and the loads on the pallets have to be comply with dimensions' limitations of the AGV (Dematic, 2018)(appendix IX) . This results in inflexibility in handling in discontinues type products in processes. Another disadvantage is that products have to be taken in the drive direction which requires more space and time. If pallets are not always the form the same type or the load is not always within the dimensions of the pallets it is recommended to implement measuring machines to determine whether the AGV could pick the pallet (appendix IX). This to decrease the amount of deadlocks in the process. In figure 13 the AGV forklift applications are shown.

Figure 13 Standard forklift AGV (Dematic, 2018)

Appendix VI INTERVIEW RESULTS COMPANY ONE

Appendix VII INTERVIEW RESULTS COMPANY TWO

Appendix VIII INTERVIEW RESULTS COMPANY THREE

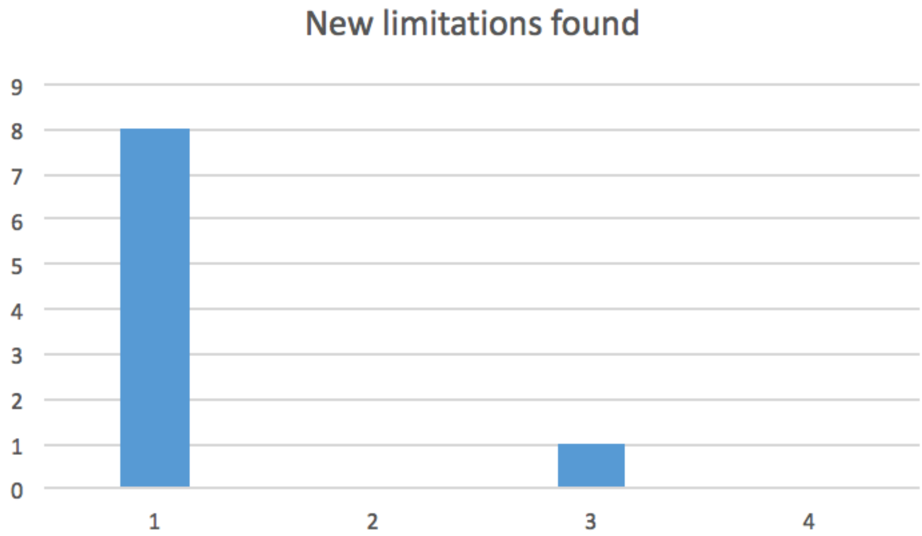
Appendix IX INTERVIEW RESULTS COMPANY FOUR

Appendix X MANUFACTURING LIMITATION ANALYSIS

Interviews	Company one	Company two	Company three	Company four	Results
limiting requirements	aisle width and A further limitation might be the necessity for contemporaneous order picking in the same area	Predefined area	Predefined area of pallet	Predefined area for pallets (precisely placed)	Predefined area for the pallets (4x)
	mixed traffic is challenging, since forklift truck drivers have to respect some rules (Not following these rules jeopardizes the success of an AGV project).	Predefined pallets (dimensions have to be known)	Wifi	Required space	Predefined pallets (4x)
	Concrete floor, evenness tolerances in accordance with DIN 18202,	Enough building space/ aisle width	Floor specs	Loading and unloading is not possible or sufficient	Required space within the warehouse (3x) and the order picking at the same area
	Permanent Wi-Fi connection between server and AGVs	Loading and unloading is not possible or sufficient	Loading and unloading is not possible or sufficient	Pallet types (because they have to be defined). They have to be scanned before pickup.	Mixed traffic if forklift drivers do not respect the rules (1x)
	Defined pick-up positions required • Lateral pick-up positioning requirement depending on pallet types, truck configuration… (typical range +/- 20 mm)		Clean floor	Dirt on the floor	Floor specs (2x)

	• Pick-up positioning requirement in drive direction typically lower (flexible pick-up using AGV truck sensors)				
	Yes, the maximum dimensions must be specified for system design. Limits depending on AGV type to be used and pallet weight (max. for stacker AGV about 2 m).				Wifi (2x)
	There are limitations on the available truck types (limited AGV portfolio compared to the available range of manual forklifts). Thus, there might be limitations on residual capacity, maximum lift heights, etc. in comparison with manual forklifts.				AGV portfolio (1x)
	Loading and unloading is not possible or sufficient				Loading and unloading insuffcient (4x)
	Loading and unloading is not possible or sufficient				Clean floor (2x)
	8	0	1	0	9

Appendix XI SATURATION OF INTERVIEWS MANUFACTURERS



Appendix XII PICTURES LUIK

Appendix XIII Pictures Arnhem

Appendix XIV PICTURES EINDHOVEN

Appendix XV FINANCIAL CALCULATION MODEL EXPLANATION

The first step is determining how many pallets could be processed by forklifts and AGVs per hour and day. Therefore, the performance of the forklifts/AGVs and the average distance must be known. The average distance will be divided by the time required to move the pallet by a forklift or AGV. This leads to the average pieces per hour and this could be multiplied by the working hours to obtain the pieces per day.

In the second step the required forklifts/AGVs will be calculated. This is done by dividing the average volumes by the performance of Forklifts and AGVs. This is done for the average volumes and peak volumes.

In the third step the costs will be calculated since it is known how many forklifts and AGVs are required in the specific case. The Labour costs are determined by the multiplying the labour costs with the hours worked. However, within the peak moments workers are working while they are for example only required for a couple of hours and not all the working hours. Within this model you could chose whether the labour contracts are flexible or not. If the labour contracts are flexible the labour used in peak hours will only be taken into account. If the labour contracts are not flexible the labour costs in peak hours will be taken into account over the working hours per day. Due to the contract limitations you have to hire someone for example for eight hours instead of the three hours you need the employee. The building costs are determined by the used space of a forklift or AGV. The required space for a forklift/AGV is determined and multiplied with the required amount of forklifts/AGVs. The energy usage is determined by the usage of the forklifts/AGVs multiplied with the energy costs. The maintenance costs are determined by multiplying the average yearly costs by the amount of forklift/AGVs. Purchase is calculated by purchase price multiplied by the amount of forklifts/AGVs. Other costs consist of two parts. The first part is yearly costs which contain cost for damages for example. The second part is one time costs which contain changed infrastructure for example.

The costs per year are known now for the forklifts and the AGVs the financial measures could be calculated. However, first the tax and inflation have to be included. The costs will increase every year with the inflation rate and the costs will be deducted with the tax rate. The NPV will be calculated with these costs. The first step is determining the PV of the two technologies by dividing the costs of the two technologies by the discount rate (WACC) over the lifecycle of the technology. These costs will be summed and divided by the lifecycle. This will give the average discounted costs per year for both the technologies. The costs of the AGVs will be subtracted from the costs of the forklifts and will lead to the yearly costs savings. The investment costs of both technologies will also by calculated and subtracted from each other over a period of ten years. The yearly costs savings over ten years will be added to determine the NPV. Furthermore, the IRR is calculated by determining the NPV for different kind of discount rates and is shown in a graph where could be seen when the IRR will be zero. The ROI is determined with the non discounted costs and the compensated investment (investment AGV- investment of forklift). Also the lifecycle time is taken into account. The calculation period is for ten years. If one of the technologies is only working for five years, it has to be bought two times. In this calculation is assumed that it could by bought for the same price as in the initial case. The payback rule is also calculated with the non-discounted profits and is calculated by dividing the compensated net investment costs by the yearly benefits.

Appendix XVI ANALYSIS OF FINDINGS REGARDING FINANCIAL MODEL BY MANUFACTERERS

Appendix XVII CALCULATION MODEL INPUT

Input — Orange must be filled in — Blue must be checked but not necessary changed in every case

Warehouse input	
Average volume [piece/hour]	1
Peak volume [piece/hour]	1
Average peak time [hours per day]	1
Forklift driver labour cost per hour [Euro]	€ 1,00
Costs building euro per [sqm/year] incl maintenace and energy use	€ 200,00
WACC [%/year]	8,6%
Inflation [%]	1,8%
Tax rate [%]	25,0%
Amount of stops in process (example weight/diminsions in the middle)(must be between 0 and 2)	0
Working hours per day	16
Working days per year	312
Energy cost [euro per KwH]	€ 0,12
Building Length	1
Avg. Distance travelled [Per piece][only deliver not driving back]	1
Flex contract of drivers [If not flexible then you always hire employees for the working hours per day]	○ Yes ● No

Performace input		Forklift	AGV
Energy usage [kWh/hour]		4,5	4,5
Maintance cost [Forklift/year]		3000	2100
Economical life cycle [Years]		5	10
Purchase price [Euros]		15000	85000
Residual value of the equipment [Euros]		0	0
Other one time costs (installation for example) [Euro]		0	1000000
Other yearly cost (think of damages etc) [Euro/year]		10000	0
Performance picking, driving 10 meters and dropping pallet [seconds]	● Manual performance	31	34
Time per meter after the first 10 meters [Seconds/Meter]		1,3	0,6
Performance picking, driving 10 meters and dropping pallet [seconds]	○ Researched performance	19	47,5
Time per meter after the first 10 meters [Seconds/Meter]		0,3	0,75

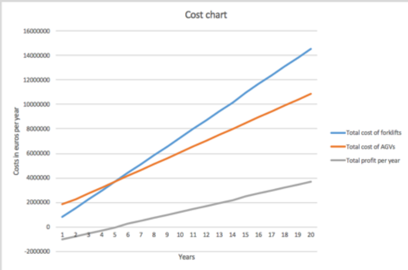
Appendix XVIII Financial model forklift output layout

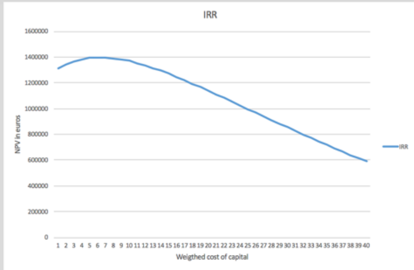
Results implementing manual forklifts only		
Required forklifts		5
Investment cost [euro]		€ 76.000
Average yearly variable cost over lifecycle [euro]		€ 723.926

Appendix XIX FINANCIAL MODEL FULL AGV IMPLEMENTATION LAYOUT

Result implementing AGVs only		
Amount of required AGVs in this situation		9
Investment costs [euro]	€	1.782.000
Average yearly variable costs for operation	€	474.956
Average cost reduction per year excl purchase	€	248.970

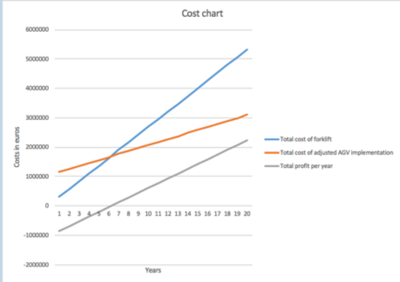
Financial measures		
Net Present Value [euro]	€	1.298.838
Non discounted Return On Investment over life cycle [%]		204%
Payback time [years]		5,1

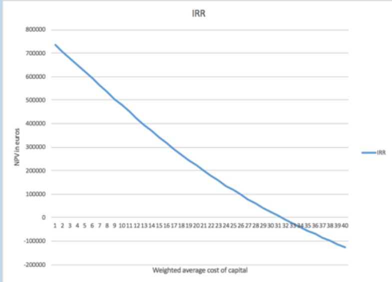




Appendix XX FINANCIAL MODEL OUTPUT LAYOUT ADJUSTED AUTOMATION

Result adjusted automation	
Amount of required forklifts in this situation	0
Amount of required AGVs in this situation	9
One time costs Forklift	€ -
Variable cost per year Forklift	
One time costs AGV	€ 800.000
Variable cost per year AGV	€ -
Required investment [euro]	€ 1.398.500
Average yearly net costs	€ 102.159
Average cost reduction per year	€ 161.787
Financial measures	
Net Present Value [euro]	€ 539.750
Return On Investment over life cycle [%]	202%
Payback time [years]	6,2





Appendix XXI Interview hub manager Luik

Appendix XXII INTERVIEW PROCESS ENGINEERS LUIK

Appendix XXIII Interview health and safety manager Luik

Appendix XXIV Interview hub manager Arnhem

Appendix XXV INTERVIEW HEALTH AND SAFETY MANAGER ARNHEM

Appendix XXVI INTERVIEW TEAM LEADER EINDHOVEN

Appendix XXVII INTERVIEW MANAGER CUSTOMER OPERATIONS BENELUX

Appendix XXVIII INTERVIEW ENGINEERING DEPARTMENT

Appendix XXIX Interview engineering department

Appendix XXX INTERVIEW ENGINEERING DEPARTMENT