Implementation of Automated Guided Vehicles in a Logistical Setting

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Preface

Dear reader,

In front of you lies my bachelor thesis ‘Implementation of Automated Guided Vehicles in a Logistical Setting’. This report concludes my bachelor study in the field of Industrial Engineering and Management at the University of Twente. This research has been conducted at the automation department of Toyota Material Handling NL.

I would like to thank Toyota Material Handling Nederland for giving me the opportunity to perform my graduation assignment under their guidance. I experienced that the staff at Toyota were always willing to help me. I especially would like to thank Paul van Veldhuizen, my internal supervisor, for his help, feedback, and guidance.

Furthermore, I would like to thank my university supervisors Leo van der Wegen and Wouter van Heeswijk for their useful feedback during the execution of this research. Their suggestions improved the quality of my work significantly.

I hope you enjoy your reading.

Tristan Otten

July 2020

Management Summary

Introduction

Toyota Material Handling (TMH) is a company that among other things sells and implements automated guided vehicle (AGV) systems that can automatically transport items within a facility. TMH mainly sells these systems to industrial clients who have standardised production environments that AGVs can work in. However, TMH wants to expand its business and also wants to sell AGV systems that can work in logistical settings as distribution centres that are less standardised and have other challenges. We determined that the main problem was the identification of items to be moved by the AGVs. The identification is for an AGV knowing what items it has to pick up, at what precise locations and to what locations it has to bring the items to. Toyota Material Handling asked us to create a strategy to improve the identification to enable for efficient implementation of AGVs in logistical settings.

Approach

To solve the problem, we started this research by first familiarising ourselves with the topic of AGVs. After having learned all the basic knowledge on the topic, we examined a case study of the implementation of AGVs at a distribution centre by TMH, which was one of their first projects with AGVs in a logistical setting. Next, we examined what could be done differently compared to the identification process we observed at the distribution centre. We investigated what solutions could work to improve different stages within the identification process. After that, we decided what solutions were best out the ones we gathered based on identified weight and criteria. Lastly, we generalised the selected solutions and combined them to create one strategy. Our goal was that our strategy could be used to decide on what solutions for the identification process fit best for automation projects of new clients depending on the encountered situation at the client.

Conclusions and recommendations

The result of this study is that we gave insight into how the identification process by AGVs could be changed. We delivered a generalised strategy that applies to all sorts of new AGV implementation projects to decide what automation solutions should be chosen in the execution of the automation project. We delivered an overview of solutions available with 19 different possibilities to shape the identification process. Providing this insight into how the identification process could be changed is already valuable in our opinion. A list of 16 criteria is created, this list can be used to evaluate automation solutions. In a logistical setting, the activities/flows can be summarised to cross-docking, storing products, and order picking. Based on these three flows, we created a decision tree model that illustrates the generalised strategy we developed. By answering fixed questions, the model indicates what the appropriate automation solutions should be. The decision tree model excels at answering the complicated question of how automation should happen in easy to follow steps.

Taking the findings of our study into the broader applicability than TMH, companies in the AGV industry could benefit from understanding the concept of identification related to AGVs. Understanding what is going wrong with solutions in current AGV implementation projects in terms of the concept of identification by AGVs is key in the search for solutions. How to discover other solutions to the experienced AGV related problem as a business can be done in different ways. However, we experienced that splitting up the process in phases increases the ability to look thoroughly into the problem. For evaluating automation possibilities, the criteria we identified could be applied.

We recommend TMH to use the decision tree model strategy we created as a tool in future projects in logistical environments and only deviate from the strategy when there are very convincing reasons for this. The decision tree model gives good guidance to help to select the solutions that can be used best.

The goal of this research was to create a theoretic strategy model. We recommend TMH to start using the model in practice and experience how the theoretic strategy works in reality. We suggest TMH to change the model in the future when our theoretic model does not match with new situations/activities encountered in practice. When an encountered activity would not match with one of the functions of cross-docking, storage or order picking, we advise to add this activity into the model and select adequate accompanying solutions for the situation.

Also, TMH could alter the applied solutions in the strategy in the future when the suggested theoretic solutions do not work as well in practice as intended. When this would be the case, TMH should choose another solution that would work better and change the related conclusions in the decision tree model.

Next, we suggest that the decision tree model in the future should be adapted to innovations in the logistical sector. For example, AGVs improve over the years and these improvements could affect what identification strategy is best.

We recommend TMH to make use of the knowledge gained on all the solutions that are available for changing the identification process. The goal of this research was to improve the identification process, and a large part of this improvement is giving insight into how the process can be changed to what TMH is doing today.

Table of Contents

Reading Guide

This reading guide is created to enable the reader to better understand the structure of this bachelor thesis. We will give a short description of what the content is of each chapter.

Chapter 1 | Introduction covers the introduction of the bachelor assignment. The chapter introduces, among others, an introduction to the company, the problem description, the research goal, the problem solving approach, and the research questions.

Chapter 2 | Capabilities of AGV systems and conditions for the implementation of AGVs covers information about what AGV systems are and how they work. Concepts related to AGV usage are introduced and conditions needed for AGV usage are stated.

Chapter 3 | The current situation at the distribution centre covers a case study about an AGV project at a distribution centre combined with information about logistical environments. Among other things, the chapter covers how the identification process at the distribution centre takes place.

Chapter 4 | Changing the identification process covers how the identification process can be changed. In the chapter, the identification process is divided into several phases and the variety of solutions available for the identification are discussed. Also, criteria to evaluate solutions on are identified.

Chapter 5 | Generalising solutions into one strategy covers the generalised identification strategy we created. The chapter states why certain solutions are chosen to be part of the generalised strategy and how logistical setting can be generalised.

Chapter 6 | Conclusion, discussion and recommendations covers what can be concluded about our research. Also, our recommendations to Toyota Material Handling are listed here and a discussion is part of this chapter.

List of definitions

In this thesis, we might use some terms that are unknown to some readers. Therefore, we created this list of definitions to enable readers to better understand the text.

Automated guided vehicle	An automated guided vehicle is a mobile robot that can follow markers or wires, or uses lasers to navigate itself. They are mostly used in industrial applications to move materials around in a facility.
Identification	Knowing three things, where to pick-up, what load of goods and where to deliver that load of goods.
Internal flow	Internal flows are flows of products that are moved within an organisation but to different business locations of that organisation.
Load carrier	The item used for transporting and storing products on/in. For example, a pallet, a box or a roll container.
Logistical environment	A logistical environment is a setting that facilitates the processes of receiving products from a producer or other logistical partner, temporarily storing the products, and thereafter shipping/distributing the products.
Manual unloading	Not automated unloading but manual by staff using an electric pallet truck or forklift truck.

List of abbreviations

In this thesis, we use abbreviations of words to enable for a more convenient reading experience. Although the abbreviations are mentioned in the text, we want to present this overview to enable for a quick lookup of the meaning of an abbreviation.

3PL = Third-party Logistics Provider

AGV = Automated Guided Vehicle

ATLS = Automatic Truck Loading System

ATUS = Automatic Truck Unloading System

DC = Distribution Centre

IRR = Internal Rate of Return

MCDA = Multiple Criteria Decision Analysis

NPV = Net Present Value

RCB = Roll Container Built

RFID = Radio-Frequency Identification

SKU = Stock Keeping Unit

TMH = Toyota Material Handling

1 Introduction

1.1 Introduction to Toyota Material Handling

The company that we will investigate at is Toyota Material Handling (TMH). Material Handling is the process of the movement of goods inside an organisation. TMH offers products/services that range from selling or leasing manual forklift trucks, consulting on material handling issues to implementing fully automated material handling systems. These systems involve automated guided vehicles, AGVs in short. The AGVs are the main topic of interest in this research. The department that is responsible for this within TMH is called Logistics Automation.

1.2 Research motivation

In the current product line, AGV systems are frequently sold items. Currently, AGVs systems are mainly sold for taking care of material handling issues in a production environment. These production environments are particularly suitable for automation due to the high possible degree of standardisation. TMH has identified what requirements are needed for applying AGV systems in production environments. They name these 'their touching points'. For these touching points, TMH understands what actions to take when these requirements are not met to still make automation possible.

However, because this company is always searching for ways to expand its business they also would like to provide AGV systems suitable for a logistical environment which we define as:

A logistical environment is a setting that facilitates the processes of receiving products from a producer or other logistical partner, temporarily storing the products, and thereafter shipping/distributing the products.

The main example of this is a distribution centre (DC) and this is the particular environment this research will focus on. This brings new challenges in installing AGV systems because in a logistical environment there is often less standardisation, there are many more different products, there are often different load carriers used, and identification is more difficult which briefly is the finding of a load carrier by an AGV. TMH would like to investigate these new challenges and come up with solutions to them to be able to sell AGV systems suitable for a logistical environment.

1.3 Problem description

The management problem TMH gave us is described as follows:

"The ability to implement AGV systems in a logistical setting by the department of Logistics Automation at TMH is insufficient and should become sufficient."

TMH has currently not enough knowledge on how to properly implement AGV systems in a logistical setting without a lot of problems. At the moment, they have a few projects in logistics but they are characterised by problems that do not occur in a production setting. There are more requirements for the implementation of AGVs in a logistical setting but TMH does not have the knowledge what these requirements and its associated solutions are.

This project will focus on requirements and associated solutions related to the **identification of incoming flows of goods.** What this implies and how we arrived at this problem we will explain in the next section.

1.4 Problem identification

We made a problem cluster to gain more insight into the problems occurring in the implementation of AGVs in a logistical environment. From this, we derived the core problem we deal with during this project. The cluster we created is the result of observation, interviewing and reviewing documents from TMH. It reflects how we see the problems at TMH. When sources about problems contradicted, our own view on the problems determined how we would handle the contradiction.

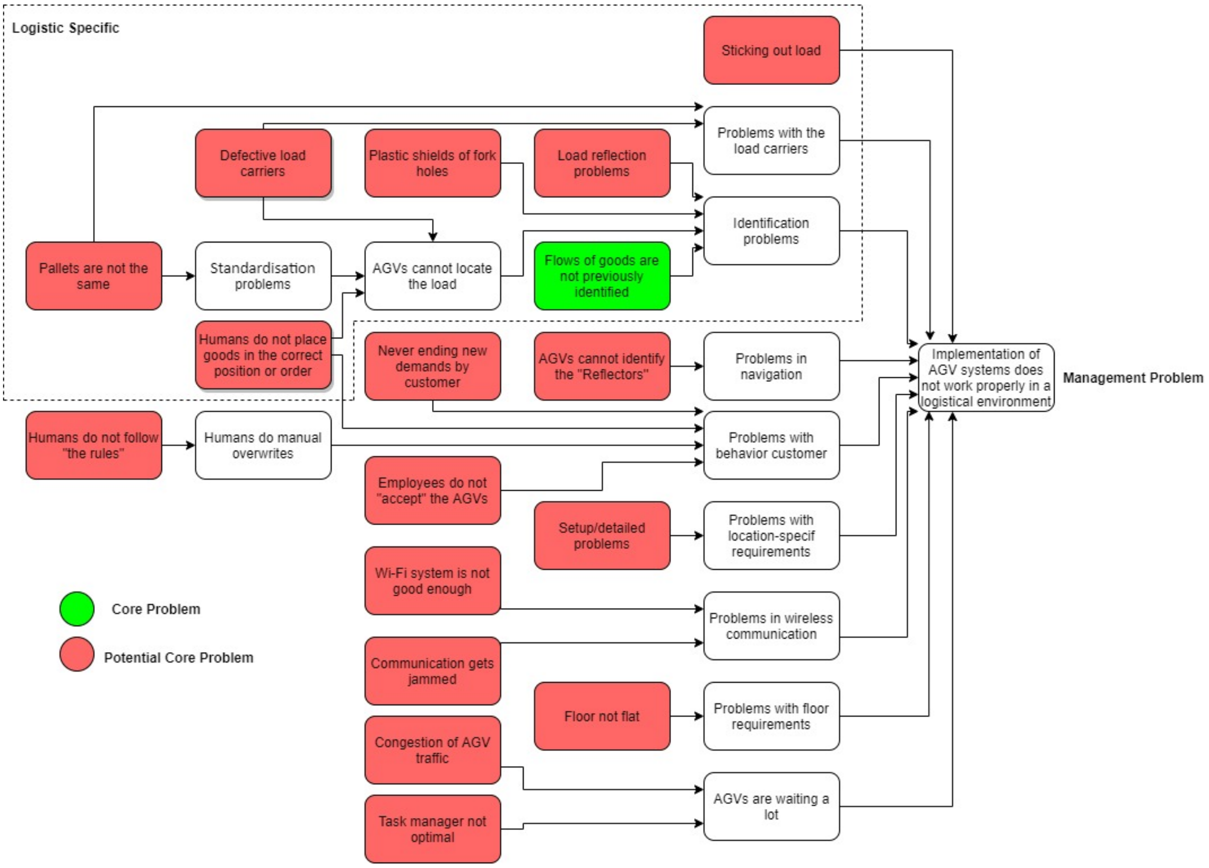

Figure 1.1 | Problem Cluster

First of all, more detailed descriptions of the problems from the problem cluster can be found in Appendix A: Cleaned up list of problems**.** This cluster can be split up in two parts. One part that relates to problems for automation using AGV systems in general and one part of problems that are logistic specific. Also, a lot of potential core problems have been identified. With automation, a lot of potential problems occur because numerous factors influence automation. Solving/investigating all these is not possible in the time available for this project. Therefore, choices have been made to select the problem this research will focus on. Considering that TMH strongly prefers improvements in the logistic specific problems and already has solutions in place for most of the problems relating AGVs in a production setting we will search for the core problem in the logistic part. This leaves 7 potential core problems that influence the implementation of AGV systems in a logistical environment.

According to Heerkens & Van Winden (2017), a problem cannot be the core problem if we cannot influence it. For the problems of “Load reflection problems” and “Plastic blocks of fork holes” applies that these are AGV technology-related problems. These problems are therefore out of the scope of this project because of the lack of time and no specific knowledge on these topics. Next, according to Heerkens & Van Winden (2017), we should select the problem that has the best cost-benefit ratio. The ‘Sticking out load’ problem refers to problems with non-conveyable items. However, because solving this problem only solves a rather small side problem we will not choose this as the core problem. For the problems of “Pallets are not the same” and “Defective load carriers’’ a potential solution already exists. Namely, placing pallets on so-called ‘carriers pallets’ but this potential solution is not yet implemented in the strategy of TMH. However, it is estimated that the potential benefit of this measure is not that large because solving this will still not make full automation possible.

This leaves the problems of ‘Humans do not place goods in the correct position or order’ and ‘Flows of goods are not previously identified’ as problems. Of those is **‘Flows of goods are not previously identified’** the most appealing problem to select. Solving this problem will have the best cost-benefit ratio for TMH is the opinion of me and the management of TMH.

The definition of this core problem is as follows:

Flows of goods are not previously identified: New goods, this can be pallets, containers, carts or other items coming into the system from earlier logistic processes are not previously identified. Here, ‘identified’ means that it is known what the exact location of the pallet is, what products are on the pallet and where the pallet needs to be dropped off.

1.5 Research Goal

The goal is a strategy to enhance the automation possibilities by improving the identification of incoming goods in different situations in a logistic setting as efficiently as possible. This strategy will depend on the degree of previous identification in the process. To be more clear about the concept identification from the core problem definition we define identification as:

Identification = Knowing three things, where to pick-up, what load of goods and where to deliver that load of goods.

Also, identification depends on whether the requirements are to have individual information, semi-individual information or batch-specific information of the logistical process. For example, if five out of ten pallets from an incoming truck (semi-individual) or all pallets (batch-specific) are the same this changes the strategy for automation needed. Other factors influencing this strategy will also be described.

We propose to make a step-by-step overview of the strategy used in the selected case study. Subsequently, we will improve and generalise this solution so that it can be applied as a general logistic automation solution, this will be in the form of a decision tree model.

Summarising, the deliverable in mind is a generalised strategy to make identification of incoming goods into a logistical setting possible.

1.6 Measurement of norm and reality

To make the core problem measurable we set a norm for the core problem and describe the reality of the problem.

Norm: A generalised strategy for complete identification of incoming flows of goods.

To make automation possible, the AGV system should know where to pick up what incoming pallet and where to drop it off. To make this possible, the system needs information on every individual pallet, we learned from interviewing stakeholders. Thus 100% of the goods, pallets or roll containers should be identified. TMH wants the approach to achieve this to be generalised.

Reality: A case-based approach that seems suitable is chosen by TMH to solve the identification problem. However, this is inefficient and results in implementing problems.

TMH has recently started implementing AGV systems in a logistical environment. Resulting, is the fact that they do not yet have the desired knowledge on how to do this. Currently, they are carrying out projects case-based, TMH tries to solve the identification problem by choosing an approach that seems the most suitable at that particular client. This approach is inefficient and often results in problems when the chosen approach does not work out.

1.7 Problem solving approach

To solve the core problem, we chose to apply the methodology of D3: Do, Discover, Decide as part of the Managerial Problem Solving Method (MPSM) (Heerkens & Winden, 2017). Applying this methodology, we decided that we first have to learn more about AGVs in general. Continuing, the approach of our study will be to investigate one case study of the first big AGV project of TMH in a logistical environment. This project can be seen as a pilot for TMH in a logistical environment. We will learn how identification is achieved here. We decided to use the case study approach because:

- We will have a clear starting point for the project.
- We can easier introduce concepts related to automation an AGVs with the case study as an example.
- We prevent ourselves from staying too long in the beginning phase of our study by finishing off the case study as an intermediate deliverable to move forward to the next phase of the project.
- We limit the scope of the project.

By the time we completed our case study, we will be going to search for alternative ways of identification. Thereafter we will make a generalised strategy for identification of based on the solutions we found and selected. The generalised strategy will be theoretic because due to the timeframe of 10 weeks of this project we cannot validate whether the strategy works in practice.

Phase 1 | Gathering information about AGVs

We will start the project by collecting more information about the implementation of AGV systems to provide a proper introduction to the topic of the project. We are going to describe the capabilities of AGVs in detail. We will look into the current basic conditions for the implementation of AGVs TMH already has identified. We will investigate how the detecting and pick up of loads works and how AGVs navigate.

Phase 2 | Performing the case study

Next, we will analyse the problem further by investigating the case study of the implementation of AGVs in a distribution centre that is the first big assignment of TMH in a logistical environment, focussing on the identification process. We will combine the introduction of theory with describing the case study. We will describe the activities conducted at the DC. We will look into the role of TMH in the DC. After that, we will look into the variety of products at the DC. Next to that, we will describe the working environment of AGVs at the DC. Besides that, we are going to describe the identification at the DC in full detail.

Phase 3 | Variety of solutions available for identification

In phase 3, we will look into the variety of solutions available to the problems on identification relating to the case study. We will break down/summarise the process in standardised steps what is happening during the process. We are going to search for alternative ways to identify incoming goods. We will do this by looking at the identification process of other logistical companies, researching the latest innovations, and doing literature research on the topic. Lastly, we will provide criteria to help evaluate the potential solutions on we found to the identification problem.

Phase 4 | Generalise the identification process

Next, we will generalise our findings from phase 3 into a general strategy to meet the deliverable of this project, this involves generalising the logistical environment and generalising the solutions. The management of TMH will make the decision on what specific solutions we will generalise. We will advise them on that, this to be able for the management of TMH to have input into the project and steer to the outcome they prefer. We will support the decision making process with a multi-criteria decision analysis. We will describe how the decision process takes place and what the considerations are. The deliverable in mind is a generalised strategy for identification of incoming goods in a logistical environment. Due to the short time frame of ten weeks of this project, the strategy cannot be implemented into practice or evaluated and improved after testing the strategy in practice. However, we will provide recommendations to TMH on how to use the strategy when they start a new project and how they could improve the strategy we will deliver. We will test our strategy on the case study we studied and consult with an expert on the validity of our strategy.

Scope

To be more clear about the scope of this project, the goal of TMH is to make the implementation of AGVs in a logistical setting possible and effective. However, we limit ourselves to the problem that flows of good are not previously identified, this can be pallets, containers, carts or other items coming from earlier logistic processes. Our approach will be by first making one case study on how to make identification possible in a logistical environment. The logistical environments we will focus on are distribution centres. Thereafter, we will search for solutions and we will generalise our findings into a general strategy model. The general strategy model will be theoretic and not be tested in practice because of the pandemic of Covid-19 and the timeframe of 10 weeks of this project.

1.8 Research questions and designs

For each phase of our problem solving approach, we defined the main research question. In this section, we state what these research questions are and what the sub-questions to these questions are to help to answer the main research question. Besides, we state how we plan to answer these questions

1. **What are the current capabilities of AGV systems and conditions for the implementation of AGVs?**
    a. What are the capabilities of AGVs?
    b. What are the surrounding conditions for AGVs usage?
    c. How do AGVs move loads?
    d. How do AGVs navigate?

This research question aims to learn what AGVs are and what are basic needs for the implementation of AGVs. we think it is important to start at the basis of what AGVs before going deeper into the problems related to them. Not everyone will be familiar with the AGV topic. Therefore it is needed to introduce AGVs more. Without being introduced to AGVs, the following chapters could be hard to understand. The research on this question will be descriptive. We will answer the sub-questions by qualitative data gathering through observation, interviewing and literature study. Working AGVs will be observed in combination with interviewing staff working with the AGVs. Literature research will be performed by studying academic sources on AGVs. Besides, internal documentation of TMH is a valuable source of documentation for literature research.

2. **What is the current situation at the distribution centre related to AGVs?**
    a. What are the AGV-related activities at the distribution centre?
    b. What is the role of TMH at the distribution centre?
    c. What flows of products are there at the distribution centre?
    d. In what environment work the AGVs at the distribution centre?
    e. How does the identification process work at the distribution centre?
    f. What are problems related to identification at the distribution centre?

This research question aims to discover what we can learn from our case study and what the role of AGVs is at the DC. We want to check how theory and reality match. Learn what the exact setting is involving our problem. This research question will be descriptive. Sub-questions A, B, and C we will answer by combining theory from literature study with observations and interviews at the DC. The remaining sub-questions we will answer by observation and interviewing only. This because these questions are very specific to our case and therefore this will not be described by literature.

3. **What is the variety of solutions available for the identification process of AGVs?**
    a. In what phases can the identification process from the distribution centre be summarised?
    b. What identification processes solutions are available?
    c. What criteria are there to evaluate the solutions on?

This research question aims to learn what the alternative solutions to the identification process are from the methods used at the distribution centre. We want to research how the identification process can be changed. We want to achieve this by first breaking down the identification process into phases. Subsequently, we will zoom in on each individual phase and research what solutions are available for conducting a phase. Lastly, we want to identify criteria to help evaluate the potential solutions we find. We will answer sub-question A by continuing on our findings of research question 2. Sub-question B, we will answer by doing literature research and visiting other logistical companies. Sub-question C, we will answer by combining literature claims on evaluation and interviewing of relevant stakeholders.

4. **How can the solutions be generalised into one general strategy?**
    a. What is the decision process to select what solutions to use in the generalised strategy?
    b. How can the logistical environment be generalised?
    c. What solutions are selected to be part of the generalised strategy?
    d. How can the solutions be generalised into a generalised strategy?

This research question aims to create a generalised strategy for identification based on the findings about the identification process and solutions available for the identification process found in answering earlier research questions. The generalised strategy will be illustrated in a decision tree model. Before we create this generalised strategy, we first answer the sub-questions about generalising the logistical environment and about the decision on what solutions to use. We will answer the sub-questions by continuing on the results from research question 3. For deciding what the set of solutions implemented in the strategy will be, we will discuss with the management of TMH.

2 Capabilities of AGV systems and conditions for the implementation of AGVs

In this chapter, we will elaborate more on AGVs. We will answer the following research question in this chapter: “What are the current capabilities of AGV systems and conditions for the implementation of AGVs?”. The goal of this chapter is to introduce readers to the AGV topic. Therefore, if one is already familiar with the AGV topic one can continue to Chapter 3. This chapter is structured as follows:

- Section 2.1 describes the capabilities of AGVs
- Section 2.2 describes the surrounding conditions for AGVs
- Section 2.3 describes how an AGV moves load carriers
- Section 2.4 describes how an AGV navigates
- Section 2.5 summarises the chapter

2.1 Capabilities AGVs

In this section, we will explain what AGVs are, for what activities AGVs are used and what the advantages and disadvantages are of using AGVs.

An automated guided vehicle (AGV) is a mobile robot. AGVs are used in the business of material handling. Material handling is all forms of internal logistics, the transportation of flows of goods within a company (TMH, n.d.). Grundlund (2014) defines internal logistics as: “All activities and processes connected with managing the flow of materials (and adherent information) within the physical limits of an isolated facility”. Moved materials can be for example pallets, rolls, racks, carts, and containers. Applications and environments AGVs excel in are characterised by medium-throughput/volume, repetitive movement of goods over a distance, regular delivery of stable loads, when on-time delivery is critical and late deliveries are causing inefficiency, operations with at least two shifts, and processes where tracking material is important (Ullrich, 2014). In this study, we focus on AGVs that act as automatic forklifts. The advantages of using AGVs are according to TMH and Groover (2008):

- Optimisation of flows of goods
- Mitigating the effects of labour shortages
- Avoid the high cost of not automating
- Safety
- Decreasing damages
- Increased efficiency of staff deployment
- Increased energy efficiency
- Reduced labour costs
- Improved product quality
- Reduced lead time

Naturally, there are also disadvantages to using AGVs. Grundlund (2014) summarises these as follows:

- Lack of flexibility
- The high cost of equipment/financial justification
- Reliability of equipment

- Software-related problems, such as poor documentation
- Integration of equipment into existing systems
- Lengthy implementation and potential dips in service level during it
- Poor user interface and need of training to operate systems

2.2 Surrounding conditions for AGVs

In this section, we introduce the procedure used for implementing AGV systems and state the requirements needed for working AGV systems.

TMH uses a standard procedure when they start implementing an AGV system at a client. The procedure consists of five steps and is as follows:

1. **Surrounding conditions =** Making sure that the surrounding conditions (touching points) needed for automation at a client are achieved.
2. **What place in the logistical process =** Deciding what place/part of the logistical process will be automated.
3. **Determine the layouts =** Determining what the layout of the AGV system would look like.
4. **Determine the flows =** Determining what flows of goods will be moved by the AGVs.
5. **Detail the flows =** Detailing how the flow of goods will be moved.

TMH states that there are important surrounding conditions needed for the implementation of AGV systems. These conditions they derived from the requirements needed for implementing AGV systems in a production environment. Currently, TMH names them their five touching points. These are:

1. **Wireless communication**

For the implementation of AGVs industrial Wi-Fi is needed. Office Wi-Fi will most often not be good enough because the AGVs use Wi-Fi to communicate with the system that controls and monitors all AGVs. If the AGV loses connection to this system, it will stop moving because it would otherwise be moving blind. Therefore, always having a good Wi-Fi connection is a crucial requirement for AGV implementation (TMH, n.d.).

2. **Navigation**

Most of the current generation of AGVs use lasers to navigate and determine their location. With a laser, an AGV searches for reflectors to reflect the laser back to itself. By this, the AGV can determine its distance from the reflector. By getting reflections back from multiple reflectors the AGV can determine its exact location. For this, the AGV has to receive reflections from a minimum of three different reflectors due to triangulation. From this, it becomes clear that reflectors are crucial to an AGV's navigation. Therefore, a requirement is that it should be possible to mount enough reflectors in the area where AGVs operate, this is not always possible in for example cramped spaces or areas that would have other objects blocking off the reflectors (TMH, n.d.).

3. **Standard load carriers**

Load carriers are the objects that products are placed on to move the products more safely, ergonomically and cost-effectively. For example, pallets or roll containers. AGVs cannot handle different sized load carriers mixed together because the AGV uses the standard dimensions of the load carrier to detect it. Dimensions of EUR-pallet differ from for example a CHEP pallet or a Stringer pallet. Without the standard dimensions, the detecting cannot happen. If the detecting would be possible, there would be another challenge. The forks of the AGV should be adjustable to adjust to the different sizes of the fork holes of the different load carriers, this is currently not possible. Therefore, a requirement for the implementation of AGVs is a standard load carrier (TMH, n.d.).

4. **Flat floor**

The floor that AGVs operate on has to be completely flat. This because AGVs detect load carriers with small tolerance and lasers. If the floor would not be flat, the difference in height could make the difference in detecting the load carrier or not. However, the floor should not be slippery. A slippery floor results in spinning of the wheels of an AGV. When this happens, the AGV thinks that it has covered more distance than it has, this results in navigation problems (TMH, n.d.).

5. **Acceptance by humans**

Humans should accept AGVs. Automation is very dependent on people that are involved in it. When people do not work together with the AGV in the proper way the automation will fail. People should for example always place loads in the same spot or use the same procedure. Rules related to working with AGVs should always be followed, this is not naturally achieved. People could fear that they will be replaced by an AGV and thus could sabotage the effectiveness system. Therefore, it is key that people feel heard in an automation project and that they stick to the discipline involved in automation (TMH, n.d.).

2.3 Moving load carriers

In this section, we will explain what procedure AGVs use to pick up and to drop off load carriers. We will also explain what concepts are involved in moving load carriers with AGVs

2.3.1 Picking up load carriers

In contrast to a manual forklift, an AGV cannot simply drive up to a load carrier and pick it up. An entire procedure is involved in picking up a load carrier. Starting with the AGV receiving the assignment from the system to pick up a load carrier. The AGV receives the exact location of where the load carrier is according to the system and drives to this location. Subsequently, it positions itself for the load carrier. Next, the AGV scans to find the load carrier at the exact location where it should be according to the system. It positions its forks in line with the forks holes of the load carrier. Thereafter, it checks whether the fork holes of the load carrier are not blocked. If this is not the case, the AGV will slowly move into the fork holes until the load carrier locates at the correct location around the forks. Next, the AGV will lift the load carrier and drive off. The AGV communicates to the AGV system that it picked up the load carrier. If the AGV observes that a part of the procedure cannot be carried out for some reason or the result from an action is different

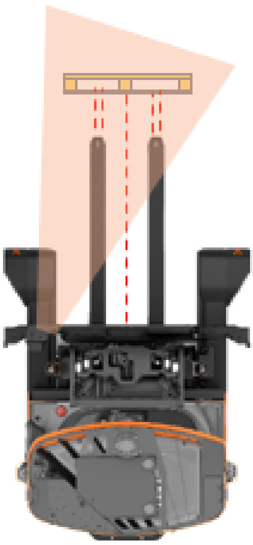

Figure 2.1 | AGV scanning load (TMH, n.d.)

than the AGV expected. The AGV will stop executing the task. An alarm goes off and an operator has to check what is wrong to resolve the issue.

2.3.2 Dropping off load carriers

An AGV also has a standard procedure for drop off load carriers. Starting with moving to the location where the load has to be dropped off. When the AGV arrives at this location is positions itself in front of the unloading spot. Then it detects whether the spot is empty or not. No obstacle or other load should be in the planned spot. If the AGV detects the spot is clear it will slowly drive forward to move the load carrier into the spot. Thereafter, the AGV drops off the load carrier. Lastly, it moves out of the fork holes of the load carrier. As with picking up load carriers, between all these operations, there are checks whether the operations are performed in the right way.

2.3.3 Concepts in moving load carriers

TMH classifies the following concepts/issues in the process of moving load carriers (TMH, n.d.):

Detect = Detect load before pickup

Stuck = Detect stuck load when loading

Presence = Secure load during transport

Slip = The slipping away of load during transport

Push = Detect obstacle at the place of unloading

Clearance = Detect top of a stack or a horizontal beam before unloading

Al these actions have corresponding error messages. Most of the above concepts have even multiple to specify the specific issue to that action. These error messages are monitored and stored by TMH is so-called black boxes. A black box is a recording of the actions of an AGV up to, including and after the error message. It enables TMH to track how often errors occur and provide information on why they occur.

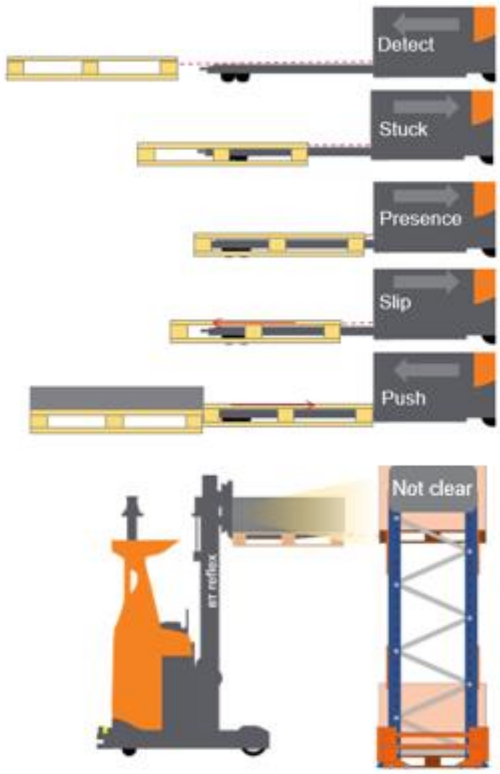

Figure 2.2 | Concepts AGV load, (TMH, n.d.)

2.4 Navigation by AGVs

In this section, we will explain how AGVs navigate and how the AGVs prevent bumping into other objects.

2.4.1 Introduction navigation

The AGVs at the DC use lasers to navigate themselves. By the usage of simultaneous localisation and mapping, the AGVs make a 3D map of their environment. The AGV system needs to know where the static and the dynamic object in the system are to make collision-free AGV traffic possible. For example, an AGV can ride into stationary pallets, other AGVs, humans or walls. Naturally, this should be prevented. However, the system does not have to know what object is blocking its path. An AGV reacts the same if a human or pallet is on its path, it stops. Only the geometry of that object in its surroundings matters (Akman & Jonker, 2012). The AGV system makes a map to manage this all.

2.4.2 Layers navigation map

The first layer of the map the AGV system creates is called the static map. The map consists of static objects like fixed machines and walls, this map is fixed (Shaik et al., 2017). However, the environment the map is representing is not only static due to day-to-day operations. According to Shaik et al. (2017), the dynamic objects in the map can be classified as high-dynamic or low-dynamic. High-dynamic objects are objects that actively change location in the view of the AGV. These are for example humans or other moving AGVs. Low-dynamic objects, which are also called semi-static objects, are objects that are static in the view of the AGV. These are object like pallets objects around the AGV. From these objects, a so-called temporary map is created (Shaik et al., 2017). Based on this temporary map an AGV can alter its behaviour. For example, when an AGV is riding from point A to point B but suddenly it observes a human is standing in its way, this will result in slowing down by the AGV and eventually a standstill until the human moves out of its way. For the current generation of AGVs, it is not possible to automatically plan a new route around an object (TMH, n.d.). For example, ride around the object as a manual truck would do. The object blocking the AGV will have to move before it will continue moving. Combining all temporary maps of each AGV creates the current map of the entire AGV system. The current map gives the entire overview of what the systems things where each individual object in the system is. The system knows the exact location of each pallet and AGV in the layout.

2.4.3 Match map with reality

A very important issue with AGV systems is that the current map created by the system should exactly match reality. When for example a pallet is transported manually from location A to location B by an operator this transportation is not automatically recorded. This means that the system still thinks that the pallet is at location A and not at location B. When thereafter an AGV arrives to pick up the pallet at location A, it cannot locate the pallet because the pallet is moved and a malfunction in the system occurs. An important note on this is that a displacement of a pallet does not have to be big to result in a malfunction. From interviews, we learned that displacement of 7.5 centimetres already can result in malfunctions of the system.

2.4.4 Manual interference

When a human interferes and starts to control an AGV manually to resolve malfunctions or move goods, the controlling system of the AGV is overwritten. However, in the current map of the system, the AGV will stay at the exact location is was overwritten for safety reasons. That could result in the blocking of other AGVs. After controlling the AGV manually, the AGV has to be added to the automatic system again, this operation is called inserting. An operator starts the automatic system of the AGV by pushing a button. First, the AGV orientates itself by searching for reflectors. Subsequently, the AGV checks whether its functions and systems work accordingly. Thereafter, the operator brings the AGV to a familiar location in the system. When the AGV has enough information about its location the operator can set the AGV loose and the AGV is in automatic mode again.

2.5 Summary

In this chapter, we extended the knowledge of the reader on the topic of AGVs and answered our research question of “What are the current capabilities of AGV systems and conditions for the implementation of AGVs?”. AGVs are used in the internal logistics of a company. Using AGVs reduce the labour costs of a company and among others excel at repetitive tasks.

However, the usage of AGV systems is limited by several factors. Lack of flexibility and the high cost of equipment are some of these factors. The conditions for the implementation of AGVs that TMH states in their five touching points are: Wireless communication, navigation, standard load carriers, flat floor, and acceptance by humans. We described how AGVs move load carriers in Section 2.3. AGVs navigate by creating a 3D map of their environment that they constantly update.

3 The current situation at the distribution centre

In this chapter, we will present findings from our case study of the implementation of AGVs and the identification strategy used at a distribution centre. We will answer the following research question in this chapter: "What is the current situation at the distribution centre related to AGVs?". We provide the theoretical basis needed of what a logistical environment and its relating concepts are. We complement this with describing the situation at the distribution centre and how theory and practice match. This chapter is structured as follows:

- Section 3.1 describes the activities conducted at the distribution centre
- Section 3.2 describes the role of TMH at the distribution centre
- Section 3.3 describes the flows of products at the distribution centre
- Section 3.4 describes the working environment of the AGVs at the distribution centre
- Section 3.5 describes the identification process at the distribution centre
- Section 3.6 describes the problems of the identification process at the distribution centre
- Section 3.7 summarises the chapter

3.1 Activities in the distribution centre

In this section, we state what activities are conducted at the distribution centre. As we have defined earlier in Chapter 1:

A logistical environment is a setting that facilitates the processes of receiving products from a producer or other logistical partner, temporarily storing the products, and thereafter shipping/distributing the products.

Activities conducted in a logistical environment, which we also refer from now on to logistical setting, distribution centre or warehouse, are receiving, put-away, storage, order picking, packing, marking, staging, and shipping (Roth & Sims, 1991). Receiving refers to the receiving of goods. Put-away is the activity of transporting the incoming unit loads to the storage locations (Tompkins, 1996). Storage refers to the storing of the goods. Order picking refers to the collecting of goods that make an order. Packing refers to the packaging of the goods in for example boxes or on pallets. Marking refers to the procedure of marking the outgoing goods with for example a bar code to make tracing the goods possible. Staging refers to storing the goods before shipment, often nearby the shipping area. Shipping refers to the transportation of the goods out of the warehouse. The essence of the logistical operations at the DC is to manage two flows. The first flow is the material flow of physical products. The second flow is the managing of the information needed for the material flow to be controlled, planned, and performed (Harrison & van Hoek, 2008). A warehouse management system is used for this task. At the DC, the activities the AGV system carries out is the staging and partly the shipping. We provide more detail on these activities in Section 3.4.

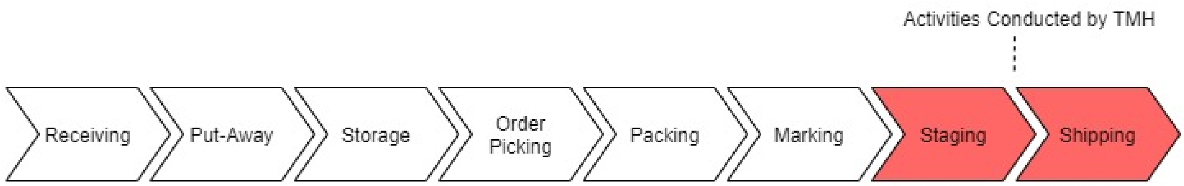

Figure 3.1 | Activities Distribution Centre based on (Roth & Sims,1991)

3.2 Role TMH at the distribution centre

In this section, we explain what role TMH has at the distribution centre and factors that influence their performance.

In the distribution centre, TMH has the role of a third-party logistics provider (3PL). A 3PL is an organisation that is hired by another organisation to conduct its logistical processes (Baruffaldi et al., 2020). As a 3PL, TMH has to handle limited information provided by its customer to operate its AGV system at the client. The result of this all is a suboptimal performance at the client in terms of enhancement of costs and working times in general (Baruffaldi et al., 2020). This is also the case for TMH at the DC. Baruffaldi et al. (2020), made factors influencing this sub-optimal performance concrete. These factors are stated in Figure 3.2.

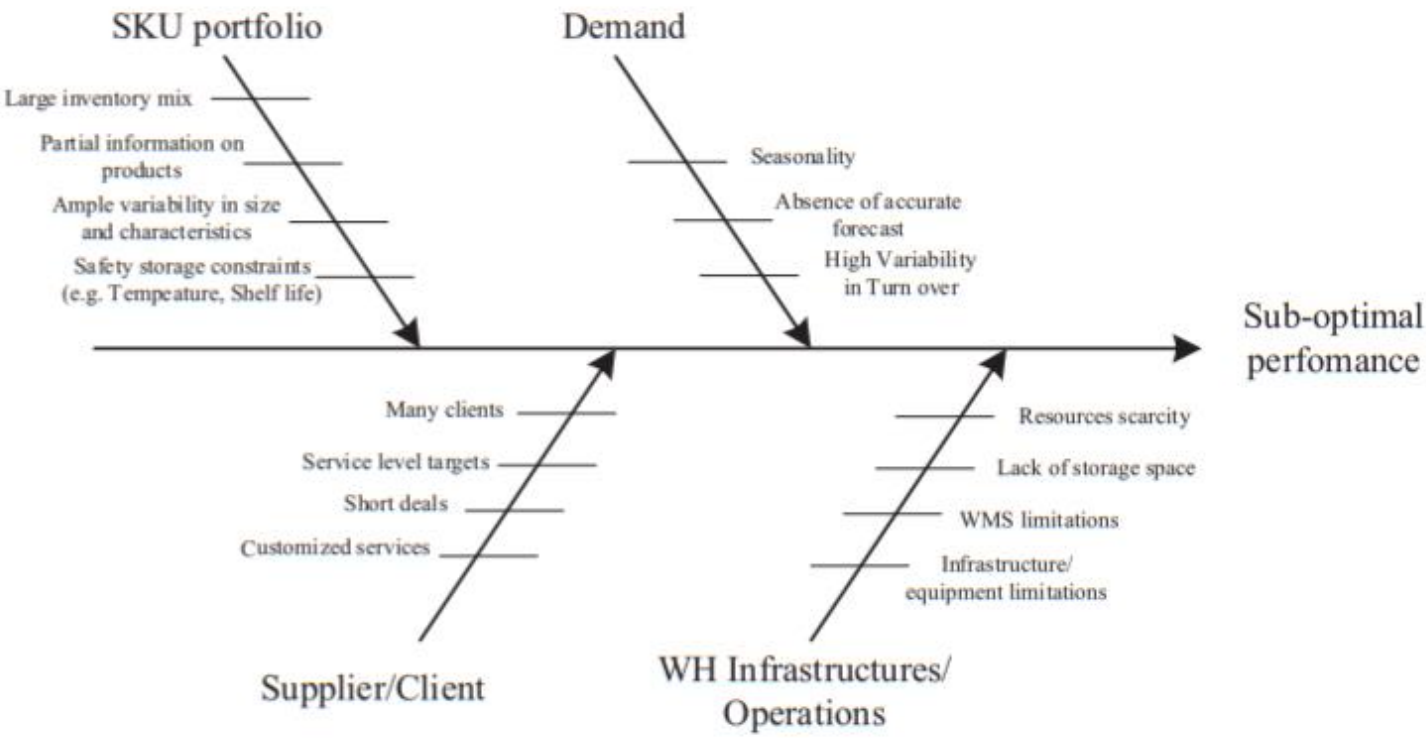

Figure 3.2 | Empirical fish-bone diagram to classify issues of 3PL warehouses, (Baruffaldi et al., 2020)

From the factors stated in Figure 3.2, TMH experiences the factors of ample variability in size and characteristics and infrastructure/equipment limitations having the biggest impact on their sub-optimal performance at the DC, this according to staff directly involved in the project.

TMH is at the DC challenged by the ample variability in size and characteristics of the products moved. Load carriers that have the products on them variate. Their dimensions are not consistent. Multiple sizes in load carriers have to be moved at the DC. However, the particular SKUs on the load carriers do not have much impact on the performance of the system is our conclusion from conducting interviews. A SKU is the abbreviation of Stock Keeping Unit, it is a specific quantity of a certain product, for example, one pallet or box. It is a concept in inventory management to identify products (Marketing Termen, 2020).

Infrastructure/equipment limitations impact the performance of TMH at the DC. Although TMH is constantly updating its AGV software, AGV related issues in the operation keep occurring. Also, TMH is limited by the layout of the DC provided by their client. AGV traffic is not the only operation performed at the DC. Machines and other objects are placed in the layout of the DC. Therefore, the most efficient layout for the AGV process is not achieved. Here, the most efficient layout for AGVs would be one that minimises the distance needed to be travelled but also prevents congestion to occur. A trade-off between these two factors has to be found because one cannot optimise both at the same time.

3.3 Flows of products at the distribution centre

In this section, we will explain how the distribution centre processes different flows of product and how products are being traced during the process.

The DC we are investigating is one that distributes consumer products which includes mainly food products. The kind of product to be stored varies. Products can be for example perishable, hazardous, fragile or heavy (Varila, Seppänen, & Suomala, 2007). Also, products may differ in dimensions, storage conditions, economic value, ergonomics, and life cycle (Manzini, Bozer, & Heragu, 2015). Therefore, different products have to be handled differently (Baruffaldi et al., 2020). Our DC has four different flows of products. We have a flow of products incoming on pallets incoming from producers, a flow of products incoming from other DCs, a flow of products incoming products on dollies (which are small carts), and a flow of non-conveyable products. From these four flows, only the first flow arrives automatically at the AGVs. The other three flows of products arrive manually to the AGVs.

Flow 1	Pallets from producers
Flow 2	Products from other DCs
Flow 3	Dollies
Flow 4	Non-Conveyable products

Table 3-1 | Flows of Products

3.3.1 Flow 1

The first and biggest flow of products into the DC is the one coming from the producers. TMH handles this flow of products only in the final stages. Therefore, we will describe the first part of this flow without much detail because the activities conducted here are not executed by TMH and thus less relevant to the research. The products enter the system by manually unloading the pallets from the trucks with the usage of an electric pallet truck. Subsequently, the pallets with products are entered into an automatic system that stores and divides the products from the pallet. This happens at the 2nd level of the DC. So this is not visible in Figure 3.5 we created. The location of the products is tracked by the warehouse management system. Thereafter, roll

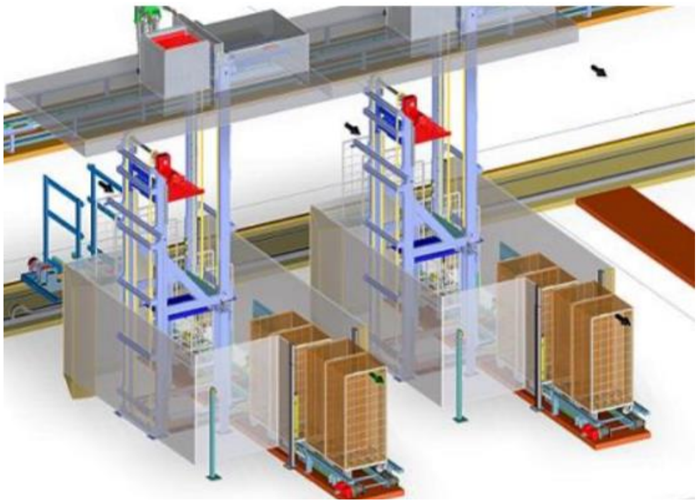

Figure 3.3 | RCB Stations

containers are picked/filled automatically by roll container built (RCB) machines. Each machine has a related lane with guiding rails to store the produced roll containers in. The combination of the machine and the lane is called a roll container build station. The RCB stations can be found in Figure 3.5. From this point on the roll containers get handled by the AGVs of TMH.

3.3.2 Flow 2

The second flow of products, incoming from other DCs, enter the DC at a truck dock connected to the cross-dock area of the DC. From getting unloaded from the trucks, the roll containers are directly driven to and placed into lanes with guiding rails from where they can be handled by the AGVs.

3.3.3 Flow 3

The third flow of products, the dollies, enter the DC at a truck dock connected to the dollies area of the DC. In this area, storage locations exist to temporary store the dollies. When a dolly is needed for an order, the dolly is manually picked. Then the dolly is driven to and placed in a lane with guiding rails from where it can be handled by the AGVs.

3.3.4 Flow 4

The fourth flow of products, the non-conveyable products, enter the DC in the same way as flow 1 does. However, these products cannot be picked automatically on roll containers due to their non-conveyable characteristics. Therefore, these products are picked manually onto roll containers and these roll containers arrive at the 1st level by the Non-Conveyable elevator. Thereafter, the roll containers are placed by operators into the same lanes with guiding rails as used for the cross-dock area. From that point, the roll containers get handled by the AGVs.

3.3.5 Guiding rails lanes

The lanes that the flow of products are placed in are crucial to the operation. Especially the lanes from flow 2, flow 3 and flow 4 because in these lanes roll containers are placed manually. To improve the roll containers positioning, the lanes are separated by metal guiding rails on the floor. This makes sure that the horizontal displacement and skewing of the roll containers cannot happen. Besides, there are markers on the guiding rails to indicate the exact location where a roll container has to stand to an operator.

Figure 3.4 | Lane with guiding rails

3.3.6 Control points of the flows

To monitor the progression of SKUs in the warehouse the SKUs pass a set of control points. Often systems features in warehouses monitor where SKUs pause, are handled and stored. Locations in the aisles and racks are known (Baruffaldi et al., 2020). In the DC, there are also control points to track SKUs in the warehouse. We named these control points to create insight into the process. In this section, we describe the control points until the products are waiting for AGV transport.

The first control point is when the products come into the system. The barcode on the products gets scanned to update their status to entered into the warehouse management system. The next control point depends on the flow of products. Starting with the first flow, because a large part of the activities for this flows are not executed by TMH and thus not relevant. We describe the next control point that involves TMH. Being, the point that a roll container comes out at the RCB stations. The warehouse management system updates the status of the roll container to waiting for AGV transport. For the other three flows this the process to arrive at this control point is a little different.

For flow 2 and flow 4, the barcode of an incoming roll container gets scanned by an operator. This roll container can come from the non-conveyable elevator or a truck. The operator gets the information from the warehouse management system to at what lane to place the roll container. When the operator places the roll container into the lane, he scans the barcode positioned above the lane. The status of the roll container is updated to waiting for AGV transport.

For flow 3, the barcode of an incoming dolly gets scanned by an operator. This operator gets the information from the warehouse management system to at what location to store the dolly. Subsequently, the operator transports and stores the dolly to this location. Thereafter, the operator scans two barcodes. The one on the dolly and one positioned above the storage location, this marks the next control point. The status of the dolly is updated to stored, with the data on at what location because of the scanning of the two barcodes. Next, when a dolly is needed for an order, an operator scans the barcode on the dolly and the one positioned above the storage location. This updates the status of the dolly to that it left storage. The operator gets the information from the warehouse management system to in what lane to place the dolly. The operator places the load in the lane and scans the barcode positioned above the lane. Now the dolly is ready to be transported by an AGV. The status of the dolly is updated to waiting for AGV transport.

3.4 The working environment of the AGVs at the distribution centre

In this section, we describe the working environment of the AGVs at the distribution centre.

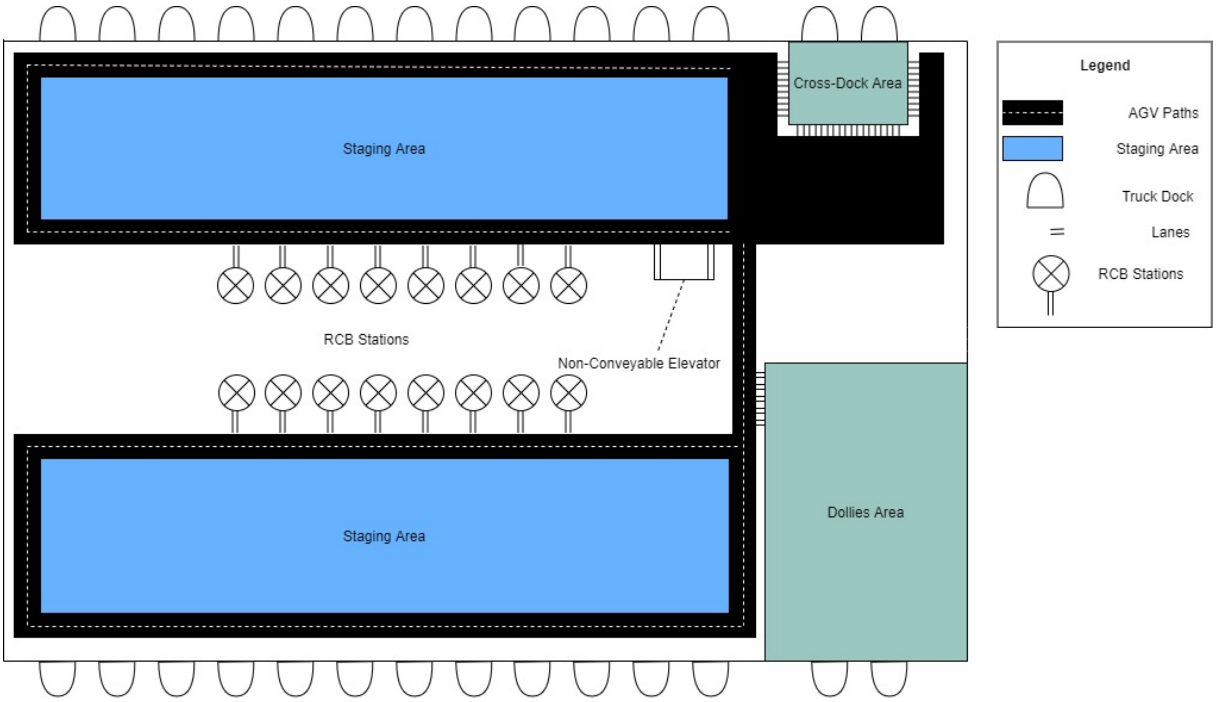

Figure 3.5 | Map distribution centre 1st level

3.4.1 Activities AGVs

In the previous section, we described the four flows of products until the point they are ready to be picked up and moved by an AGV. The AGVs in the DC operate at the 1st level. In this environment, the AGVs conduct the activities of staging and partly shipping. This is where all flows of products come together. Flow 1 comes from the RCB stations. Flow 2 comes out of the lanes from the Cross-Dock Area. Flow 3 comes out of the lanes from the Dollies Area. Flow 4 comes out of the Non-Conveyable elevator and merges with flow 2.

AGVs transport a load of products out of the lanes of the remaining three flows to the staging areas and drop off the load of products at the planned spot. Each load of products is part of an order that eventually have to be shipped together. Therefore, each load of products that is part of an order is staged close to other loads of that order in the staging area to increase efficiency. Eventually, all products from the different flows of products arrive at the staging areas in this way.

When a truck arrives at a truck dock, it is time to ship the order out of the DC. The AGV system then gives the assignment to the AGVs to bring the loads of products of the order from the staging area to the truck dock. Then the products get loaded into the truck manually.

3.4.2 Control points

The monitoring of the products continues when the products have to be picked up by an AGV. The AGV system couples an AGV to a load of products waiting in a lane. When the AGV picks up the load, the status of the load of products is updated to 'moved' by the corresponding AGV. When the AGV drops off the load of products into the staging area the status again gets updated. The status becomes waiting in the staging area with the data on the exact location.

When an AGV picks up the load of products again to transport it to the truck dock, the status of the load is again updated to 'moved' by the corresponding AGV in the warehouse management system. The arrival at the truck dock is also registered into the warehouse management system. The status becomes waiting for loading. The final operation is the loading of the products into the truck. To track this, the trucker scans the barcode on the load of products and the barcode positioned above the truck dock, this marks the exit of the products out of the DC into the truck. The status becomes updated to departed from the distribution centre.

3.5 Identification process at the distribution centre

In this section, we further focus on the identification process at the distribution centre. As we stated earlier, identification is knowing three things for an AGV, where to pick-up what load of goods and where to deliver that load of goods. We learned that from the four flows of products at the DC, flow 1 arrives automatically to the AGVs and flow 2, flow 3 and flow 4 arrive manually.

3.5.1 Automatic flows

The automatic flow of products is convenient to AGVs. The arrival of the products is completely standardised because they arrive by an automated system. This has the benefit that the products always are presented to the AGV system at the exact same spot, this makes the location of the product known. What the products are is also known. This information is provided by the warehouse management system that controls both flows to the AGV system. Lastly, the destination for the products is known. This location in the staging area is determined by the warehouse management system that controls which staging area is used for what order, making the products of both flows automatically completely identified.

3.5.2 Manual flows

Starting with the identification of products incoming from the non-conveyable elevator and other DCs by truck in the cross-dock area. These products are on roll containers which are individually marked with a barcode. When an operator unloads or receives a roll container, he scans the barcode on it. This gives the warehouse management system the information what the products on the roll container are. In advance, it is planned what order the roll container is a part of. So it is known where the roll container has to be transported to. From scanning the barcode, the operator reads on its scanner to what lane he has to bring the roll container. He has to put the roll container into the lane with very high precision. A deviation of more than 7.5 centimetres already results in disruptions, this results that the total tolerance is 15 centimetres. Subsequently, the operator scans the barcode on the roll container again and the barcode positioned above the lane. This registers the roll container into the AGV system. The AGV system now knows theoretically the exact location of the roll container in the lane. Why this is not always turning out to be true we explain in the next section.

The identification of the other manual flow, the dollies, basically uses the same identification system. Therefore, we do not describe the entire process again. The only difference compared to the products arriving from other DCs is that the dollies are temporarily stored. They are not immediately put into the lanes. However, this results not in a difference to the identification process.

3.6 Problems occurring related to identification at the distribution centre

In this section, we will discuss what problem TMH encountered at the distribution centre and what problems TMH is still facing.

3.6.1 Problems at the beginning of the implementation

In theory, the identification of the four different flows of products should be fully working at the DC when the AGVs started to move loads of products 2 years ago. But in practice, this turned not out to be the case. From the three requirements for identification, TMH kept struggling with the exact location of a load. In particular from loads originating from manual flows 2, 3 and 4. It turned out that it took a long time to make all the operators at the DC aware of the precise execution needed of dropping the roll containers and dollies off into the lanes. Due to slight misplacements, roll containers would not be at the exact location the AGVs expected them to be. Also, in the lanes, multiple roll containers are placed after each other because the AGV can move multiple roll containers at once. In practice, it turned out that when a second roll container would come in it could bump the first roll container out of position. These human mistakes in combination with other problems resulted in errors.

3.6.2 Problems regarding complete automation

The reason that the flows 2 and 3 of products are not fully automated is that it is not possible to unload load carriers by AGV. Firstly, the AGVs cannot move into the trucks because there are no reflectors inside the trucks, this results in that the AGV cannot navigate. Secondly, the order of the load carriers in the truck is not known. The AGV system does not know that for example load carrier A stands at the front or the back in the truck. Lastly, the AGVs cannot scan the barcodes of the corresponding products that enter the DC. This makes it not possible for the system to control whether the correct load carrier is entering the system. This is not desirable because the DC wants to check whether the reality of products arriving corresponds with the products that should be arriving.

3.6.3 Current problems

When we jump forward to the current situation at the DC, we observe that the identification process of incoming products is working but with some error here and there. The human contribution in the process drastically improved. Almost no error occur anymore due to misplacement of loads. Issues the staff of TMH is currently dealing with is packaging plastic, reflecting materials, and software mistakes in the AGVs.

Most of the load carriers moved in the DC are covered with plastic to prevent products from falling off them. However, when the plastic packaging is applied well, it could cover the fork holes. This results in that the AGV thinks that the hole is blocked. Also, reflecting materials like recently galvanised metals could prevent the AGV from detecting the load carrier. Lastly, software problems to the AGVs is a reoccurring problem and TMH keeps improving this software.

3.7 Summary

In this chapter, a case study is performed on an AGV project from TMH at a distribution centre to summarise our answer to our research question of “What is the current situation at the distribution centre related to AGVs?”. From the main activities at the DC, the AGVs conduct the activities of staging and partly shipping. There are multiple flows of products in DC. The most important distinction between these is whether the products arrive automatically to the AGVs or manually. Logically, the manual flows are less standardised and this is the main reason that the AGVs struggle more with these flows of products. To identify the manual flows a system of scanning barcodes and placing roll containers in lanes is used. The identification requirements are knowing where to pick up, what load of goods and where to deliver the load of goods. From these, the biggest issue is the exact location of where to pick up the goods and it should be researched how this can be improved. However, TMH did deliver an AGV system that works in the logistical environment.

4 Changing the identification process

In this chapter, we will present the range of options we have for the shaping of the identification strategy. We will answer the following research question in this chapter: “What is the variety of solutions available for the identification process of AGVs?”. We first define the distinct phases of the identification process. Thereafter, we will discuss which potential solutions exist for the different phases of identification. Also, we will discuss if altering the order of phases could be beneficial. Lastly, we will formulate on what criteria to evaluate these solutions. This chapter is structured as follows:

- Section 4.1 describes the phases of the identification process
- Section 4.2 describes the variety of solutions available for the identification process
- Section 4.3 describes the criteria to evaluate the solutions on
- Section 4.4 summarises the chapter

4.1 Phases of the identification process

In this section, we will define the phases of the identification process. We learned that in the DC, there is a significant difference for products arriving automatically or manually to be collected by an AGV concerning the robustness of the identification process. From now on we will for convenience refer to flows of products arriving automatically to AGVs as automatic flows. For flows of products arriving manually to AGVs, we will refer from now on to as manual flows. To evaluate other ways of identification, we will have to make a distinction between these flows. We learned that there are no significant problems for automatic flows. The environment is highly standardised such that it resembles the conditions in a production environment. Therefore, we will only discuss the manual flows in de remaining of this chapter. Our challenge is to seek how the manual flows could be further standardised to improve the identification of these flows.

For the process of identification of the manual flows at the DC, we define the phases of Arrival, Unloading, Checking, Transport, Storage, and Placement. Besides, we define the endpoint of the identification process as the AGV Coupling Point. An overview of the phases can be found in Figure 4.1.

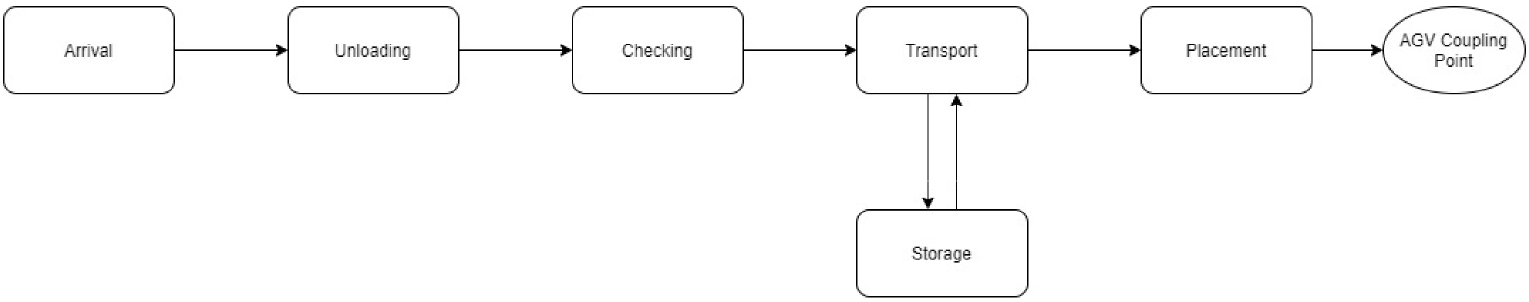

Figure 4.1 | Phases of identification of manual flows

Descriptions of what characteristics and events we define to belong to the phases:

1. **Arrival:** The arrival of products by truck. The ordering of the products inside the truck and the load carriers the products are on. Besides, we distinguish here whether individual, semi-individual or batch-specific identification is needed.
2. **Unloading:** The unloading procedure from the products from the truck.
3. **Checking:** Checking what products are on load carriers and where the load carriers have to go. Besides, we attribute the activity quality control to this phase.
4. **Transport:** The transporting procedure used to move the products. How are the products moved and the number of load carriers that can be moved at once.
5. **Storage:** The procedure of how products are stored for longer periods and how the tracking of products in storage takes place.
6. **Placement:** The procedure of placing load carriers on locations where AGVs can pick them up. The time between placement and picking up load carriers is on the contrary to the storage phase short. The phase includes what tools are available to improve placement and how the placement of load carriers is notified to the warehouse management system.
7. **AGV Coupling Point:** The endpoint of the manual identification process. The point that an AGV picks up the products and the point that requires complete identification of the incoming products to be achieved.

What the variety of solutions available are for these phases in comparison with the situation of our case study we will discuss in the next section.

4.2 Variety of solutions available for the identification process

As the structure of this section, we will for each defined phase give the method used at the DC of our case study. Besides, we will give alternative solutions to how that phase could be conducted. These alternatives come from procedures or systems used at other logistical companies, ideas from literature reviewing, ideas from TMH, and ideas of our own. In Section 4.2.8, we will give an overview of the solutions available including the advantages and disadvantages of solutions.

4.2.1 Arrival

At the DC, the products arrive by truck to the truck dock. The products are on roll containers or dollies depending on the flow of products the shipment belongs to. The ordering of the load carriers in the arriving truck is random. Besides, individual identification of the products is needed because of that none of the load carriers carries the exact same products.

In theory, products could also arrive by other modes of transport than a truck. However, in practice we did not come across such a situation and therefore we will disregard other means of transport than a truck.

Another possibility for the arrival phase is that more information about the shipment inside the truck is known beforehand. A possibility could be that it is known what the ordering of the products in the truck is. The location where what load carrier is positioned in the truck would be known. In theory, this makes scanning the barcode on these load carriers after unloading unnecessary because it would be known beforehand what products are on the load carriers. This, in combination with another measure as an automatic unloading system (Section 4.2.2) could be very beneficial. In practice, if the ordering of load carriers inside an incoming truck would be known, it is likely that the intended destination for the load carriers is also known and communicated to the warehouse management system. This, because this destination of a specific load carrier is easier to learn than its ordering within a truckload.

For a shipment between different locations of the same company, it could be possible to know the ordering of the load carriers in the truck. For shipments arriving from other companies, this is harder to achieve. For another company, this means more work to provide this information. Besides, checking the products on arrival for quality control is more desirable from shipment incoming from other companies. However, we must consider whether the additional work of documenting the ordering of products in the truck is compensated by the benefit from it. For example, in the situation of our case study at the DC, the ordering does not matter because the roll containers have to be scanned anyway and every roll container has its individual path based on that.

Next to knowing the ordering, it could be beneficial to know beforehand where load carriers from the truck have to go in the warehouse. Load carriers from the truck that are part of the same order in the DC could be positioned together in the incoming truck. This could enable for more efficiency in the unloading process because these load carriers could be unloaded together and thus less transportation is needed. We remark here that individual ordering within load carriers consisting of one load does not have to be known for this advantage to occur. However, consideration needs to made whether the additional work is compensated by the increased efficiency.

4.2.2 Unloading

At the DC, the load carriers are unloaded manually by an operator that uses an electric pallet truck. The operator drives into the truck to take the load carriers out. The operator can unload two load carriers at once. To get into the truck an automatic ramp is used. This ramp makes sure that the floors of the truck dock and the truck are on the same level.

Another possibility in the unloading phase would be to use an automatic truck loading system (ATLS). For example a chain conveyor system, roller track system or a Skate system (Driest, 2010). Systems like these have a movable surface that enables forwards and backwards moving of the load on the surface automatically. An advantage is that for loading and unloading it is no longer necessary to drive into the trailer (Esmeijer, 2013). Besides, the loading and unloading process would also get faster. The system could load and unload trucks completely at once. An ATLS only needs 2 minutes to load or unload a truck (Driest, 2010).

Figure 4.2 | An ATLS system, (Esmeijer, 2013)

However, a severe disadvantage of the usage of an ATLS is that the floors of the trailers of the trucks have to get adapted to the system. Therefore, automatic (un)loading systems can generally only be used in the internal logistics of a company. The main application is therefore internal high volume shuttle transportation (Driest, 2010). For example, transportation between distribution centres of the same company or from a production company to its separated warehouse.

Concerning AGV usage, the usage of an ATLS would make the loading and unloading process completely standardised. The incoming flows of products from the trucks would always arrive at the exact same location. This is beneficial for the identification of the products related to AGV usage. If the information of what the products are and where they have to go could be obtained before or during unloading the identification process could be drastically improved.

4.2.3 Checking

At the DC, the checking phase is conducted by scanning a barcode that is attached to the load carrier. This gives the warehouse management system the information of what is on the load carrier. The system planned in advance where the load carrier has to go and reports this to the operator. At the DC, the roll containers at the cross-docks do not get a quality inspection. This, because these are internal flows. Internal flows are flows of products that are moved within an organisation but to different business locations of that organisation. For the dollies, there is a brief inspection because this flow is from an external supplier. Among other things, it is checked whether the number of arriving dollies corresponds with the theoretical number.

An alternative to using a barcode is the use of radio-frequency identification (RFID). The usage of RFID is new in the warehousing sector and still developing. A RFID tag enables real-time tracking of products. The RFID tag transmits a signal containing where it is located within the warehouse. There is a difference between active and passive RFID tags. Active RFID tags have a built-in power source and can broadcast signals by themselves. Passive RFID tags do not have a built-in power source and can only broadcast a signal back to a reader. The costs of passive RFID tags is significantly lower compared to active RFID tags. So is the range of the signal of the tags. For our intended application we will need active RFID tags. For convenience, we will in the remainder of the text state *a RFID tag* instead of an *active RFID tag*.

On entering a facility, an incoming load carrier could already be linked to a RFID tag, this would make scanning and using a barcode redundant when the load carrier is entering the facility. The RFID tag would provide information about what is on the load carrier. The problem with this is that for using RFID tags that are already linked to load carriers on entering a facility is that those load carriers should originate from internal flows. Practically, it is not possible to achieve the linking if load carriers would come in from another organisation.

If RFID tags would not be linked to the load carriers on entering the facility, the linking could take place in the checking phase to make use of RFID in later phases of the process. A barcode that is attached to a load carrier should be scanned and the RFID tag has to be attached to the load carrier to link the load carrier and the RFID tag. The linking of the RFID tags would create additional work in the checking phase but from this could be benefited in later phases in the process.

There is a problem with the usage of RFID tags when load carriers would leave a warehouse. The RFID tags would have to be detached from the load carriers or the carrier-pallets containing the RFID tags should have to be removed. This is needed because the RFID tags have to be re-used, this would create a significant amount of additional work in the warehouse.

We refer to RFID in multiple phases of Section 4.2. Therefore, we made an overview of all information on RFID stated in de different sub-sections in Appendix B.

As a last remark for this phase, the methods required for the identification process depend on the type of shipments that come into the logistical environment. The activities in the checking phase could be reduced as a result of this. If a shipment coming into the logistical environment consist of all the same product, what we define as individual identification is not needed. Load carriers with products originating from the same shipment can be swapped between themselves without resulting in a different outcome. Only with what we define as batch-specific identification is needed. We define semi-individual identification to when multiple load carriers but not all from a shipment contain the same products. Resulting from this is that in the checking phase fewer scans could be needed. Load carriers with products could be immediately going into the transport phase without checking what the products are. In practice, only a check whether the amount of arriving load carriers in practice corresponds with the amount in theory would have to be carried out for batch-specific identification.

4.2.4 Transport

At the DC, the transportation of the load carriers before the load carriers are transported by AGVs is done by an operator on an electric pallet truck. One or two load carriers can be moved at once. The transport distance is short and the transport time very short. Also, this phase is already conducted efficiently in our opinion. Therefore it is not worthwhile to suggest changes here. Besides, this transportation phase has a minimal effect on the identification process that we want to improve.

4.2.5 Storage

At the DC, the load carriers are stored in rows that act as storage zones. Using a system of scanning a barcode that is positioned above the row and the barcode on the load carrier by an operator the warehouse management system keeps track of the row in which the load carrier is stored. Basically, two things can be changed in this phase without changing the AGV coupling point: The way the load carriers are stored and the method used to track the load carriers.

An alternative way to store the load carriers is to store them in racks. Most combinations of products and load carriers to do not allow for stacking, this results in the need for more floor area to store load carriers. The advantage of using racks is that the load carriers can also be stored vertically. This increases the utilisation of the floor area. However, some load carriers such as roll containers are not suitable for placement in racks. Therefore, whether rack storage is an option is depending on the type of load carriers used.

An alternative to track during the storage phase would be the usage of a RFID tag. When a RFID tag is linked to a load carrier, the warehouse management system automatically tracks the load carrier. This makes the steps of scanning barcodes on the load carriers and at the storage position redundant.

We refer to RFID in multiple phases of Section 4.2. Therefore, we made an overview of all information on RFID stated in de different sub-sections in Appendix B.

4.2.6 Placement

At the DC, the load carriers are placed in lanes by operators to enable an AGV to pick them up. On the sides, the lanes have metal guiding rails that prevent the load carriers to move horizontally or be skewed. On the guiding rails, markers indicate how far forward the load carriers have to be positioned. An issue in this system is that operators do not always follow the markers on the guiding rails with enough precision. Multiple load carriers can be placed in one lane. A drawback from this is that one load carrier could bump another load carrier out of its location.

The tracking of the load carriers in the warehouse management system is done by scanning the barcode on the load carrier and a barcode positioned above the lane. Summarising, there are 3 factors/problems in the placement phase: The precise positioning in the lanes, the bumping, and the tracking.

Another system than using markers on the guiding rails could be used to improve the positioning of load carriers in the lanes. This is a system that combines the usage of a mirror and bright coloured line. During the positioning of a load carrier, an operator checks in the mirror whether he still can see the bright line. If this is no longer the case, the load carrier would be out of position and the operator would have to reposition.

Another possibility to improve the positioning and the bumping would be to make a stopping edge at the end of a lane, maybe one that withdraws when the AGV arrives or one than functions as a barrier used at a rail crossing. This allows for less error in the precise load carrier placement that is needed. Also, an edge would stop load carriers from bumping out their desired location. A drawback from this is that the load carriers or the stopping edges could get damaged. For example, if wheels of a role container would bump into stopping edges, over time the wheels would get less circular. Therefore, such a solution can only be implemented when the damaging of the load carriers and the stopping edge can be limited or prevented.

Another possibility would be to only allow one load carrier into a lane, this eliminates the problem of load carriers bumping into each other. However, this drastically decreases transportation efficiency. AGVs would have to perform significantly more operations. Therefore, we already conclude that this is not a feasible solution.

A system that could also improve precise positioning and prevent bumping is the usage of a system with a conveyor belt. The idea of the system is that an operator places the load carrier onto a conveyor after the checking or storage phase. This depending on the earlier chosen layout of the process. Subsequently, such a system moves the load carrier into a lane where the AGV can pick up the load carrier. The system makes sure that the load carrier is positioned properly and the AGV can locate the load carrier. Drawbacks of such a system are that it is an expensive solution and that it requires more floor space compared to the other solutions.

Incorrect positioning and bumping could also be solved by the usage of RFID tags. When a load carrier would be positioned to be picked up by AGVs, Active RFID tags constantly broadcast their position. The warehouse management system could receive this position and pass-through this information to the AGV system. The AGVs would get notified of the position of the load carrier and could pick it up. The advantage is that no precise placement of the load carrier would be needed by the staff in the warehouse because the position of the load carrier is passed through to the AGV anyways. However, we recommend using this RFID solution in combination with the lanes with guiding rails. This, because the guiding rails are an easy solution to horizontal displacement of load carriers and prevent skewed positioning of load carriers.

A potential problem for the implementation of RFID tags would be precision. For AGVs to pick up a pallet, the precise position of this pallet has to be known. At this point, it is unknown how precise the location of a pallet could be determined. Two years ago, according to Chawla et al. (2018), the average accuracy was as low as 15 centimetres. Undoubtingly, technology will have progressed in the 2 years until now but 15 centimetres accuracy is insufficient. Namely, AGVs require a minimum accuracy of 7.5 centimetres. At this point in time, it is also unknown how the exchange between the signal of the RFID tag and the AGV itself workout. The AGV uses a special camera and lasers to localise a load carrier. Adaptation of software would be needed and it is unknown whether this combination would work.

A result of using RFID tags would be that scanning barcodes for tracking would not be needed anymore. As we already stated in Section 4.2.5, the scanning of barcodes becomes redundant because the load carrier is automatically tracked by the warehouse management system.

We refer to RFID in multiple phases of Section 4.2. Therefore, we made an overview of all information on RFID stated in de different sub-sections in Appendix B.

4.2.7 AGV coupling point

This section describes what possibilities there are to involve AGVs earlier in the process compared to the conventional AGV coupling point we observed at the distribution centre of Chapter 3. We have 2 possibilities: bring the AGV coupling point to after the arrival phase or after the checking phase.

Coupling point after arrival phase

In theory, the AGV coupling point could be moved entirely forward. AGVs would unload the load carriers directly from a truck. However, because the AGVs from TMH cannot navigate inside the trucks this solution is currently unavailable. However, maybe this will be possible in the future because there are AGVs on the market that can load trucks. Another disadvantage is that the incoming products should be completely identified on arrival. This would require a combination of earlier mentioned measures that are altogether not likely to be achieved. Load carriers should be positioned at exact standardised positions in the truck. Also, the exact information on where in the truck what load carrier is located and where that load carrier has to go has to be known before the AGV can start unloading. We conclude that loading by an AGV is easier to achieve than unloading. Because here only the navigation problem would remain an issue because the load carriers are identified outside the truck. But loading is not an activity we focus on in this research so we will leave this topic out of further consideration.

Another potential problem would be that unloading by an AGV would be slower compared to manual unloading by an operator that uses an electric pallet truck or a forklift truck. Logistical processes often have time pressure during the unloading process so this is a drawback. AGV usage in unloading would make more sense in situations where the time factor is less important. For example, overnight unloading for 1-way transport (Driest, 2010).

We also have the possibility that AGVs would only unload and stage the load carriers. This eliminates the requirements to know what is on the load carrier. After the load carriers are staged an operator could scan the load carriers to further identify them and continue in the process.

Coupling point after checking phase

In combination with the earlier measured possibility of using an ATLS (Section 4.2.2), the AGV coupling point could also be moved forward after the checking phase. The AGV could come into play when the load carriers are unloaded by the ATLS and all the required activities from the checking phase would be completed, meaning that the information of what the products are and where they have to go is provided. This can, for example, be provided by an operator scanning a barcode on each load carrier and thereby notifying the system what is on the load carrier. The information could also already be known because the exact ordering of each load carrier coming out of the truck is provided in advance. The advantage of picking up the load carriers by the AGV from the ATLS is that the locations of the load carriers would be standardised. The advantage of this is obvious.

The AGV coupling point could also be moved forward because the phases of transportation and storage could in theory be carried out automatically by an AGV. The trade-off that has to be made in this situation is that whether automating the storage in the logistical environment is cost-efficient.

For the tracking of the load carriers, there are two options. The first is to keep using the current virtual tracking system. The AGVs communicate where they pick up and drop off load carriers. Via this communication, a virtual map is made where load carriers are currently located. The other option is to use RFID. There could be an opportunity to use a combination of these systems to increase the precision of the system. However, at this point in time, we cannot judge whether this would result in increased precision or whether this would be a cost-efficient solution.

4.2.8 Overview of solutions available

To give a better overview of all solutions mentioned in Section 4.2, we arranged the solutions and included the advantages and disadvantages of the solutions. This results in the following table:

Phase	Solution	Advantages	Disadvantages
Arrival	***Know content truckload but random ordering***	▪ The existing situation at most clients ▪ No additional work required	▪ AGVs cannot immediately pick up the load
	Know content truckload + destination		▪ AGVs cannot immediately pick up the load
	Know content truck load + ordering + destination	▪ Load carriers are fully identified	▪ Additional work when the incoming truck gets loaded ▪ Incoming goods must be an internal flow
Unloading	***Unloading by manually using an electric pallet truck or forklift truck***	▪ The existing situation at most clients ▪ No additional work required	▪ Significant human labour needed
	Automatic truck unloading system	▪ Faster unloading ▪ Could allow for immediate pick up by AGVs after unloading	▪ Truck trailers have to be adapted ▪ Expensive ▪ No experience with such solutions
Checking	***Checking by scanning barcode***	▪ Proven technology ▪ Reliable	▪ No real-time tracking possible
	Checking by scanning barcode + adding a RFID tag	▪ Real-time tracing possible ▪ Theoretically, AGVs could locate load carriers using the RFID tag signal	▪ Additional human labour for adding a RFID tag ▪ RFID tags have to be recovered when load carriers exit the facility

			▪ This application of AGV tags is not a proven technology
	Checking by an already ready installed RFID tag	▪ Real-time tracing possible ▪ Theoretically, AGVs could locate load carriers using the RFID tag signal	▪ RFID tags have to be recovered when load carriers exit the facility ▪ This application of RFID tags is not a proven technology
Storage ○ *Storage specific*	***Rows***		
	Racks	▪ Increases the utilisation of the floor area	
○ *Tracking specific*	***Barcode***	▪ Proven technology ▪ Reliable	▪ Human labour needed
	RFID	▪ Automated tracking	▪ Possibly accuracy limitations
Placement ○ *Positioning and Bumping specific*	***Lanes + guiding rails with markers***	▪ Relative cheap solution	▪ Bumping possible ▪ Not all operators work with enough precision
	Lanes + guiding rails with mirror and bright coloured line	▪ Relative cheap solution	▪ Bumping possible ▪ Not all operators work with enough precision
	Lanes + guiding rails + stopping edge/barrier	▪ Bumping issue solved ▪ Improved accuracy in positioning the load carriers	▪ Possibility of damage to the stopping edge or load carriers
	Conveyor belt system	▪ Automated system	▪ Expensive ▪ Uses more floor space
○ *Tracking specific*	***Barcode***	▪ Proven technology ▪ Reliable	▪ Human labour needed
	RFID	▪ Automated tracking	▪ Possibly accuracy limitations
AGV Coupling Points	***Conventional unloading point***	▪ The existing situation at most clients ▪ No additional work required	▪ Less automation compared to other AGV coupling points
	Unloading by AGVs	▪ Complete automation of the process	▪ Current generation AGVs of TMH cannot do this ▪ Incoming goods need to be completely identified on arrival ▪ Slower unloading process

	in combination with an automatic truck unloading system	▪ Almost complete automation of the process	▪ Expensive ▪ No experience with such solutions
	Storage conducted by AGVs	▪ More automation compared to the conventional unloading point	▪ Could not be cost-efficient

Table 4-1 | Solutions available

4.3 Criteria to evaluate solutions on

In this section, we define criteria to support deciding what solutions from Section 4.2 should become part of a generalised strategy. As stated in our problem solving approach in Section 1.7, the management of TMH makes the decision what set of solutions becomes part of the strategy. The goal of the criteria we provide in this section is to give TMH insight into what factors are relevant for deciding on what solutions to use.

We decided that our criteria list consists of a mixture of criteria from literature and criteria from our own input to make sure that all relevant criteria for decision making are included in our list. In our search for criteria from literature, we used three point of views. One view being criteria based on warehouse performance. The second view being criteria based on the topic of change management in automation and the last view being criteria relevant to TMH on the topic of project management. Our opinion is that these views of criteria include all relevant criteria to evaluate the solutions on.

We did not directly copy criteria or indicators from literature but used the literature to identify the themes for the criteria. We did this because of the literature lists many detailed indicators which are either not relevant to our evaluation or not applicable for us. Therefore, our criteria list can be seen as a list of criteria themes instead of a list with direct and operationalised indicators.

Starting with criteria we derived from literature, Staudt et al. (2015) conducted an extensive literature review study of more than 40 relevant papers on the topic of warehouse KPIs. We reason that if we look into this study, we identify all relevant warehouse KPIs. We will give a brief summary of the findings of the study. The study makes a distinction on performance measures between the ‘hard’ and the ‘soft’ metrics. The hard metrics refers to direct indicators which are easily quantitatively measurable. The hard metrics have four themes: *time-related, quality-related, costs-related, and productivity-related*. Each theme has multiple corresponding indicators. For example, an indicator of the quality dimension is on-time delivery.

The soft metrics refers to indirect indicators which are either too difficult to calculate or unavailable (Staudt et al., 2015). An example of this is how to measure customer perception. Staudt et al. (2015) determined that in literature there is no agreement on ways to measure and define indirect indicators. Also, there is no consensus on all the factors that should be a part of the indirect indicators. However, the study did classify 7 themes of indicators. These are labour, value-adding activities, inventory management, warehouse automation, customer perception, and maintenance.

On the topic of change management in automation, Beck, Dzindolet, & Pierce (2002) described variables that affect an operator’s or companies’ automation usage decision. The variables reflect what factors influence the decision of using complete automation, manual or less technologically advanced solutions. The variables are *reliability, consistency, bias, attitudes, and trust.*

Lastly, criteria that are relevant to TMH concerning project management. During our project, we developed knowledge of AGV systems and the logistical sector. We also consulted with the staff of TMH to find out what criteria are relevant in their opinion. Based on this knowledge, we think that criteria of *investment costs, realised benefits, project risk, additional work staff, similarity to existing experience, and ease of implementation* are also relevant for evaluating solutions. When searching for literature on this topic, Brauers (1990) stated that with regards to the financial perspective of project management, the criteria of the *Net Present Value (NPV), Internal Rate of Return (IRR), and payback period* are relevant. Supporting the importance of the criteria *similarity to existing experience, and ease of implementation*, Gerogiannis et al. (2010) states the importance of risk management during a project, which can directly be linked to this criteria.

Resulting from this all we combined the criteria themes into one list. In combining the criteria, there was a challenge for us to select the proper mixture of criteria that are either not too broad or too detailed. Possible criteria we identified but are less relevant compared to the other criteria in our opinion we excluded. This applies to the criteria value-adding activities and realised benefits. Realised benefits is a too broad concept in our opinion. For example, financial and quality-related benefits are accounted for in other criteria.

Themes or topics that overlapped we combined to reduce the number of criteria and avoid too detailed criteria. Concerning financial criteria, we limited ourselves to the criteria of *operational cost and investment costs.* We think that the criteria of NPV and IRR and payback period are too heavily linked to operational costs and investments costs. We also combined the measures of *bias and attitudes* because these are both about personal opinions on the solutions. We combined *trust and project risk* because these measures significantly overlap. We chose to also name the new criteria project risk because this is the more clear term in general.

We decided to not add more criteria because we have the opinion that the current set of criteria include all the important factors for the decision process. Adding more criteria would create an overlap. For example, a criterion like technical feasibility seems a good criterion to add. However, when looking at the set of criteria we have we observe that technical feasibility is accounted in the ease implementation criteria.

The result is the criteria list of relevant measures suggested to change the identification process earlier in this chapter. Besides stating each criterion, we also added a description for each criterion. These descriptions are derived from the respective literature source they originate from or are our own definitions. Note that criteria are not operationalised. The reason for this we explain in the next chapter. The list of criteria can be found in Table 4-2.

Criteria	Description
Operational cost	The effect of the measure on the operational costs of the facility.
Time-related	The effect of the measure on time needed in the process.
Quality-related	The effect of the measure on the overall quality and robustness of the process.
Productivity-related	The overall effect of the measure on throughput and utilisation in the logistical environment.

Labour	The effect on manual labour required in the process by the measure.
Inventory management	The effect of the measure on the insight into inventory management and information management.
Warehouse automation	The effect on automation degree of the entire process by the measure.
Customer perception	The perception of the customer on the measure. Does the measure seem unnecessary or useful.
Maintenance	The effect of the measure on the frequency of maintenance that is needed.
Reliability	The likelihood that the accuracy of a measure is adequate to achieve the objective of automation (Beck, Dzindolet, & Pierce, 2002).
Consistency	The extent that the reliability of a measure does not change over time (Beck, Dzindolet, & Pierce, 2002).
Bias and attitudes	Favourable or unfavourable reactions to over or undervalue automated or manual control when considering the measure for automation (Beck, Dzindolet, & Pierce, 2002).
Project risk	The risk/trustworthiness that it is predictable, dependable, and inspires faith that a measure will behave as expected in unknown situations (Beck, Dzindolet, & Pierce, 2002).
Investment costs	The costs of the measure's upfront investment.
Similarity to existing experience	The impact the measure has on the current working methods and degree of experience with the measure.
Ease of implementation	The amount of work needed to implement the measure.

Table 4-2 | Criteria list and descriptions

In the next chapter, we will evaluate the solutions available based on these criteria and present these criteria to the management of TMH. We will determine what criteria are most important to the management and decide what solutions should be part of the generalised strategy.

4.4 Summary

In this chapter, we studied what alternative variety of solutions are available for the identification process of AGVs. We did this by splitting up the identification process into our own defined phases. The phases are Arrival, Unloading, Checking, Transport, Storage and Placement. We also defined the AGV coupling point. This is the point where AGVs get involved in the process. Then, we presented the opportunities there are to alter the phases in future automation projects. We listed these opportunities, including the main advantages and disadvantages of the solutions, in a table in Section 4.2.8. The section also gives a direct answer to our main research question of this chapter: “What is the variety of solutions available for the identification process of AGVs?” Lastly, we created a criteria list to help to evaluate the solutions by the management of TMH. Themes that are important in the criteria list are warehouse performance, change management in automation, and project management. The list consists of a total of 16 criteria.

5 Generalising solutions into one strategy

In this chapter, we will generalise our findings into one general strategy for identification. We will answer the following research question in this chapter: “How can the solutions be generalised into one general strategy?”. We will explain how we decided to use which solutions for identification from the previous chapter. We will generalise the situations TMH can encounter at clients with logistical environments. We will present and explain the selected solutions. Furthermore, we will present our generalised strategy based on the solutions we decided to use. This chapter is structured as follows:

- Section 5.1 describes the decision process
- Section 5.2 describes the generalising logistical environments
- Section 5.3 describes the selected solutions
- Section 5.4 describes the generalised strategy
- Section 5.5 summarises the chapter

5.1 The decision process

In this section, we describe the procedure we used to decide what solutions from Section 4.2 to use for the generalised identification strategy. We will describe the procedure that was used we will describe in six steps.

Firstly, we introduced the management individually to our problem solving approach. We made the management familiar with our definition of identification (knowing three things: where to pick-up, what load of goods and where to deliver the load of goods) and stated our phases of the identification process.

Secondly, we presented the range of solutions available for the identification process. We made sure that the management understood what the measures included and made them aware of the advantages and disadvantages. We gave the management one week the time to process all the information on the variety of solutions. Thereafter, we introduced our criteria list from Section 4.3. We stated why a criterion would be relevant for the solutions to the management.

Subsequently, we wanted to illustrate how solutions would score on different criteria to show a more detailed overview of the advantages and disadvantages of the solutions and allow for a Multiple Criteria Decision Analysis (MCDA). In general, criteria should be fully operationalised to make them measurable and to be able to assign scores to the criteria. However, we decided to not fully operationalise the criteria and instead assign scores to each criterion subjectively. We did not use an exact grading scheme.

We have four reasons for this decision. Firstly, management will only use this analysis as a tool. It is not a binding advice and we allow the management to make other decisions for their own specific reasons. This reduces the importance to operationalise because our analysis is not binding. Secondly, a lot of criteria are impossible to operationalise at this stage because they would have to score potential solutions which are not yet made concrete and the implementation of the solutions would likely be different at different future projects. Subsequently, the main goal for us is to improve the insight between the differences of solutions to the management, in other words, a relative ranking. We only added the MCDA as an additional tool but it should not be looked at as the focus of our advice. Lastly, still trying to fully operationalise our criteria would take very large amounts of time. Time we do not have

Arrival	Operational costs	Time-related	Quality-related	Productivity related	Labour	Inventory management	Warehouse automation	Customer perception	Maintenance	Reliability	Consistency	Bias and attitudes	Project risk	Investment costs	Similarity to existing experience	Ease of ilmplementation
Know content	6	7	6	7	6	6	6	6	6	7	6	6	7	7	8	7
Know content + destination	6	7	6	7	6	6	6	6	6	7	6	6	7	7	7	7
Know content + ordering + destination	4	9	7	9	7	6	7	8	6	5	6	9	5	7	6	4
Unloading																
Electric pallet truck or forklift truck	5	4	5	6	3	6	4	4	7	6	5	?	8	6	8	9
ATLS	8	9	7	8	8	6	9	8	5	8	8	?	3	3	3	3
Checking																
Barcode	7	6	8	7	6	6	6	6	9	9	9	?	9	8	8	8
Barcode + attach RFID tag	4	3	7	4	4	7	6	7	5	5	5	?	3	4	6	3
RFID tag already in place	5	5	6	7	5	7	8	8	5	5	5	?	3	4	5	3
Placement																
Lanes + guiding rails with markers	7	6	6	6	6	6	6	6	6	6	6	?	7	7	7	7
Lanes + guiding rails with mirror and bright coloured line	7	6	6	6	6	6	6	6	6	6	6	?	7	7	7	7
Lanes + guiding rails + stopping edge/barrier	7	6	8	6	6	6	6	6	4	8	7	?	6	6	6	6
Conveyor belt system	7	5	9	6	8	8	8	8	5	8	8	1	3	2	4	2
Barcode	7	6	6	6	6	7	6	6	9	9	9	?	9	8	9	8
RFID	5	6	7	7	6	8	7	7	5	6	4	?	3	5	5	3
AGV coupling point																
Unloading	7	2	6	5	7	6	8	8	5	6	6	3	1	4	2	2
Combination ATLS	9	8	8	7	8	6	8	7	5	8	8	?	4	2	3	4
Storage conducted by AGV	7	7	6	7	7	6	6	6	5	8	8	?	6	6	7	6

Table 5-1 | Scoring solutions on criteria because this research has to be executed within 10 weeks.

We gave scores to each criterion subjectively to each solution ranging from very good (10) to neutral (6) to very bad (1). We only did not give scores to the solutions in the storage phase because this would not be valuable in our opinion We also added a question mark for when we could not estimate what the effect of a solution on a criterion would be. The assigned scores can be found in Table 5-1. Thereafter, we asked the management what criteria from our criteria list are most important to them. They responded that for an automation project costs are always the most important. The budget and the business case of a client for an automation project determine what the possibilities are. The more automation and complexity, the more expensive a project becomes. Usually in the industry, a client determines its budget for an automation project based on the payback period it wants to have. The payback period is the time needed to earn back an investment. Resulting in that the investment a client is willing to make is often limited. With automation, the investment is mainly earned back by the reduction of operational costs through the need for fewer employees. Based on this, it is clear that the criterion investment costs is the most important criterion for TMH and its clients.

However, the payback period does not indicate what the savings for a client are after the payback period ended. After the payback period has ended, the operational costs are still reduced. Therefore, next to the payback period, also taking the return on investment after the payback period and net resulting NPV of the automation investment into account is useful for a client when it determines its budget. This shows the importance of the operational costs criterion for a client, but this importance is not as big as the importance of the investment costs because often only limited funds are available for the automation project at clients. Also, making this strategy for TMH, TMH does not directly profit from the reduction in operational costs of a client, this reduces the importance of the criterion.

When the budget would be no issue, complete automation should always be the focus for the identification process because this is the most convenient to TMH according to management. Complete automation increases the reliability and quality of the identification process by AGVs. However, when complete automation is not possible, the manual tasks in the identification process should be reliable and robust. From this, we concluded that the criteria of warehouse automation, quality-related, reliability and consistency are also important criteria. Other criteria are less important according to the management. Based on the management respondence, we determined weights for the criteria. We did not give all other criteria the same weight because we do not have the opinion that all less important criteria are equally less important. We created Table 5-2 to show the relative importance of each criterion.

Criteria	**Operational costs**	**Time-related**	**Quality-related**	**Productivity related**	**Labour**	**Inventory management**	**Warehouse automation**	**Customer perception**	**Maintenance**	**Reliability**	**Consistency**	**Bias and attitudes**	**Project risk**	**Investment costs**	**Similarity to existing experience**	**Ease of ilmplementation**
Weights	**0.05**	**0.025**	**0.1**	**0.025**	**0.025**	**0.025**	**0.075**	**0.025**	**0.025**	**0.1**	**0.1**	**0.025**	**0.05**	**0.25**	**0.05**	**0.05**

Table 5-2 | Relative importance criteria

Subsequently, we combined the weights and scores of the potential solutions to complete our MCDA and presented these findings. Naturally, we cannot combine a score of "?" with some weight. We resolved this issue by not taking this score into account and redistribute the other weights accordingly. The total scores can be found in Table 5-3.

Solutions	Total score
Arrival	
• Know content	6.60
• Know content + destination	6.55
• Know content + ordering + destination	6.38
Unloading	
• Electric pallet truck or forklift truck	5.79
• ATLS	5.85
Checking	
• Barcode	7.85
• Barcode + attach RFID tag	4.82
• RFID tag already in place	5.05
Placement	
• Lanes + guiding rails with markers	6.46
• Lanes + guiding rails with mirror and bright coloured line	6.46
• Lanes + guiding rails + stopping edge/barrier	6.51
• Conveyor belt system	5.43
• Barcode	7.69
• RFID	5.38
AGV coupling point	
• Unloading	4.90
• Combination ATLS	5.67
• Storage conducted by AGV	6.56

Table 5-3 | Weighted scores solutions

Lastly, the management decided what solutions would be options to use in the generalised strategy, this taking into consideration our advice. For example, a decision that had to be made was whether RFID would have a place in the generalised strategy. The outcome of these decisions can be found in Section 5.3.

Summarising, the decision process consisted of six steps. First, we made the management familiar with concepts and our problem solving approach. Secondly, we introduced the range of solutions available and the criteria list. Subsequently, we informed the management of the strengths and weaknesses of the solutions based on the criteria. Thereafter, we determined the importance of the criteria. Next, we presented what the best solutions would be when weights and scores on criteria are combined. Lastly, the management decided what solutions to use in the generalised strategy. But before we state what these decisions are we will discuss in Section 5.2 how logistical environments can be generalised.

5.2 Generalising logistical environments

In this section, we describe how we generalise logistical environments to enable ourselves to make a generalised strategy. We generalise the logistical environment by stating that TMH can encounter 3 different types of activities conducted in the warehouses of clients. Firstly, the activity of cross-docking. Secondly, the activity of storing and shipping complete load carriers products, from now referred to as storage. Lastly, the activity of order picking and creating new compositions of products on load carriers. In practice, in warehouses of clients, a combination of these activities would be encountered. A challenge is how the related tasks of these activities could be combined in the AGV implementation. In the next paragraphs, we will further define and describe these activities. Besides, we will state what tasks AGVs can perform for these different types of situations.

5.2.1 Cross-docking

In the first situation, TMH encounters a warehouse with the activity of cross-docking. The AGVs can conduct here the activity of bringing the load carriers from inbound dock to outbound dock. In practice, almost all warehouses have temporary storage buffers close to the outbound docks. These areas are also referred to as marshalling areas. A marshalling area has the goal to both increase the utilisation of truck docks and to reduce the number of truck docks needed in a facility. The concept is that when all outbound load carriers are not directly transported to the truck docks, different shipments can make use of the same truck dock. When marshalling areas are used, the AGVs can conduct the activities of transporting load carriers between the inbound docks, the marshalling area and the outbound docks.

5.2.2 Storage

In the second situation, TMH encounters a warehouse that has a storage function. We distinguish here between storage and the usage of marshalling areas that storage reflects the storing of products over a longer period in the facility. The usage of marshalling areas reflects the storing of products close to the outbound docks over a short period. Here, the AGVs could facilitate the transport of load carriers from the inbound dock to the storage and the transportation between the storage, the marshalling area, and the outbound docks.

5.2.3 Order picking

In the third situation, TMH encounters a warehouse that creates new compositions of products on load carriers. Creating new compositions of products on load carriers refers to the process of order picking. Order picking is the process of collecting and extracting products from stored larger quantities of products from a warehouse to fulfil orders. This process can be automated, as we have seen in the distribution centre discussed in Chapter 3, or can be conducted manually. A key objective for enabling AGV usage after the orders are picked is to standardise the output of ‘new’ load carriers. If this would be achieved, the AGVs could facilitate the transport of the ‘new’ load carriers to the marshalling area and the outbound dock. Also, AGVs could transport incoming products to the area where the products are picked. However, this depends on how the order picking process is designed.

5.3 Selected solutions

In this section, we describe what solutions are chosen from the solutions available presented in Section 4.2.8 to have a place in our generalised strategy. We state the most important decisions and explain why they have been made.

The first important choice that had to be made was whether the preference was to choose for manual unloading or an ATLS. The management concluded that the preference should always go to a solution that aims to achieve complete automation. Therefore an ATLS is favoured. Our MCDA also indicates that the ATLS solution is the slightly better option. However, an ATLS is an expensive solution and investment costs are important. It has the effect that if the budget of a project is inadequate for an ATLS there still would be chosen for manual unloading. Another important requirement for the opting for an ATLS is that the flow of goods should be an internal flow. This, because floors of the trailers of the trucks have to get adapted to this system. This is not the case for flows of goods coming from outside the organisation. When the requirement of internal flows would not be achieved, manual unloading is preferred.

Resulting from the decision that ATLS has a place in the generalised strategy it becomes possible that AGVs could pick up load carriers immediately after the system unloaded them. This requires the warehouse management system to know what each unloaded load carrier contains and where it has to go. The management prefers that this information would be known before a load gets unloaded from a truck. However, when this would not be possible this information could also be acquired by scanning barcodes that would be attached to the incoming load carriers.

Another choice is the one between using barcodes or RFID tags for tracking products in warehouses. RFID tags could also be used to determine the positioning of load carriers by AGVs. Here, the usage of barcodes is preferred. Our MCDA also indicates that the barcodes solution is the better option. The reasoning for the decision by the management is that the accuracy for determining the position of a load carrier to be picked up by an AGV is very likely insufficient. Thereby this potential application of RFID tags is cancelled. This results in that the usage of RFID tags has no more advantages over the usage of barcodes. Considering, that the usage of barcodes is the cheaper option and that using RFID tags would require more work for the employees in warehouses the usage of barcodes is preferred.

The last major choice that shapes the strategy is how the placement of load carriers to be picked up by AGVs could be improved when load carriers are unloaded manually. The choice was between using a system with lanes with guiding rails or a conveyor belt system. Here, the management preferred to keep using the known system of using lanes with guiding rails because a conveyor belt system would be a very expensive option and using such a system would not be worthwhile according to the management. A conveyor belt system would be too extended to design for the task at hand of transporting load carriers over such small distances only to improve positioning. Also, there are doubts whether such a system would not be significantly slower than placing load carriers manually.

If we summarise this section, we can state that for the unloading of trucks an ATLS should be preferred if some requirements are met. We concluded that the usage of RFID tags is not attracting and we opt for the usage of barcodes. Lastly, when load carriers are unloaded manually, they should also be positioned manually in a system of lanes, making a conveyor belt system instead is a too complicated and too expensive option for the task. The MCDA also supports this decision.

5.4 Generalised strategy

In this section, we will present the generalised strategy we created. We will first introduce our decision tree model. Thereafter, we will explain the basics about how the decision tree works and how TMH can use it. Subsequently, we will further zoom into the differences between the flows in the decision tree model.

5.4.1 Introduction

Based on the solutions selected to use in Section 5.3, we created a generalised strategy to make identification possible at future AGV projects in logistical environments. This strategy is illustrated by our decision tree model. The decision tree can be found in Figure 5.1. Important to note, the strategy assumes that the surrounding conditions (Section 2.2) for AGV implementation are reached at the new client. Also, we did not incorporate all smaller improvements mentioned in Section 4.2. This to prevent the strategy of becoming too complex. But for example insights in different requirements for batch or individual identification could be applied in future projects. A compact overview of the decision tree and related documented without explanation in between can be found in Appendix C. In the next sections, we elaborate more on how the decision tree model works and what the solutions stated in the decision tree involve.

5.4.2 The basics of the decision tree

After the circle shape that states 'Start', the first encountered object in the decision tree is a rounded rectangle stating Q1. Each rounded rectangle in the decision tree represents a question. Q1 represents question 1, Q2 represents question 2, and so on. The questions can be found below. Based on the answer to the question, it is determined what solution best fits the encountered situation at the client and how the decision tree progresses. The progression is represented by arrows. In these arrows, it is stated what answer is linked to the arrows. Each rectangle in the decision tree represents a conclusion with a number of a design choice that should be followed. The conclusion states how the encountered situation should be automated according to our strategy. In the decision tree, this conclusion is stated very briefly but below these conclusions are depicted in full detail. The ordering of the conclusions is based on the numbering in the decision tree model. Most often the eventual strategy will be a combination of conclusions. These conclusions should be combined to give the full plan for how the automation should be achieved.

The starting point of our strategy is distinguishing between the different activities/processes conducted in a logistical environment (cross-docking, storage, and order picking), as discussed in Section 5.2. In the remainder of Section 5.4, we will refer to these activities/processes as the different flows. To which flow the encountered situation at a client corresponds to largely determines the progression in the decision tree. However, the decision tree does converge again at some points because parts of the strategy for the different flows is the same and to keep the decision tree compact. To give more insight into what different parts of the decision tree are about the decision tree is divided into three segments. One segment about determining the automation degree that is needed for the encountered situation. One segment about determining the basic solution layout and one segment about detailing the solutions.

Complete list of questions referred to in the decision tree model:

Determining the automation degree

Q1 = What function does the flow to be automated within the logistical setting of the client perform?

Generalised Identification Strategy Model

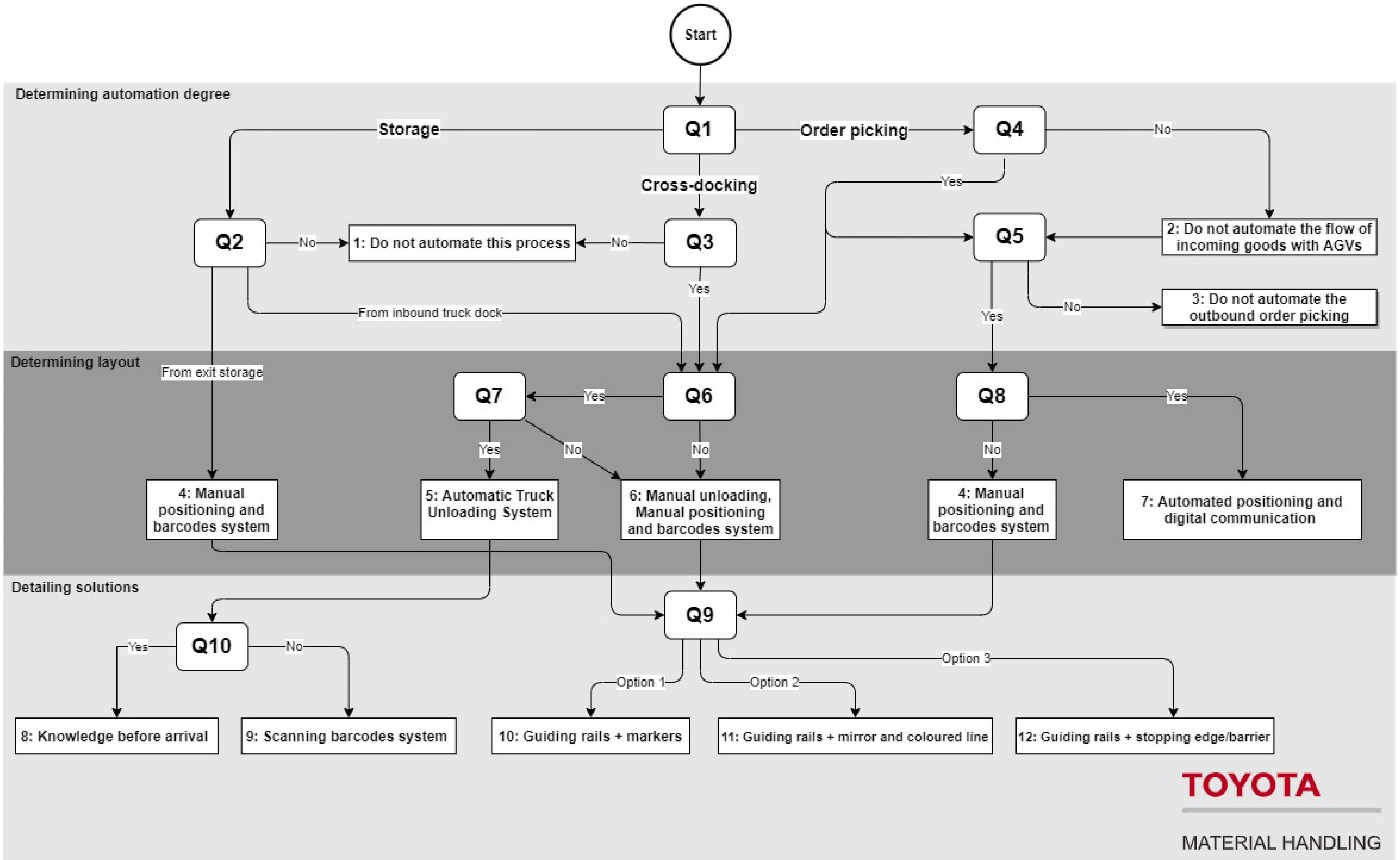

Figure 5.1 | Generalised Identification Strategy Model

Q2 = Is the business case positive to automate from a certain point in the storage process for the client with AGVs?

Q3 = Is the business case positive to automate the transportation of load carriers in the cross-docking process of the client with AGVs?

Q4 = Is the business case positive to automate the transportation of the incoming products to the order picking area by AGVs?

Q5 = Is the business case positive to automate the transportation of load carriers after order picking to the marshalling area and/or outbound truck docks?

Determining the layouts

Q6 = Are the products arriving at the inbound truck dock(s) an internal flow?

Q7 = Is the budget of the project sufficient for automatic truck unloading systems solutions?

Q8 = Is the arrival of load carriers from order picking process automated?

Detailing the solutions

Q9 = What lane positioning tool best suits the project?

Q10 = Is it achievable to acquire the information on the ordering and destinations of the load carriers inside the truck before the arrival of the truck and is the business case for this measure positive?

Complete list of conclusions referred to in the decision tree model:

1. Automation of this activity by AGVs should not be conducted.
2. The transportation of load carriers from the inbound truck dock to the order picking area/process should not be automated by AGVs.
3. The transportation of load carriers after the order picking activities should be automated by AGVs.
4. The solution applied to position load carriers for AGV transport should be a manual positioning system. A system of lanes with guiding rails should be developed. This system should allow for manual placement of load carriers by operators. To determine what products are on a load carrier, in what lane a load carrier has to go and to notify the warehouse management system of the placement of load carrier a barcodes system should be used.
5. To unload load carriers from trucks at the inbound truck docks automatic truck unloading systems should be used.
6. Unloading of the load carriers from trucks at the inbound truck docks should be conducted manually by operators. The solution applied to position load carriers for AGV transport should be a manual positioning system. A system of lanes with guiding rails should be developed. This system should allow for manual placement of load carriers by operators. To determine what products are on a load carrier, in what lane a load carrier has to go and to notify the warehouse management system of the placement of load carrier a barcodes system should be used.

7. The positioning of the arrival of load carriers is automated and so completely standardised. This should be used to inform the AGV system of the positioning of load carriers to be moved by the AGV system. The information on where a load carrier has to go and when a load carrier is ready to be picked up should be digitally communicated by the automated system from the order picking process to the AGV system.
8. A system should be made/designed that acquires the information on the ordering and destinations of the load carriers inside a truck before the arrival of a truck. This will allows for immediate picking up of load carriers by the AGVs after they are unloaded by an automatic truck unloading system.
9. A system should be developed that enables operators to scan barcodes attached to the incoming load carriers to communicate to the warehouse management system what the ordering of the load carriers is. This will allows for immediate picking up of load carriers by the AGVs after they are unloaded by an automatic truck unloading system.
10. To improve the vertical positioning of the load carriers markers should be made on the guiding rails that indicate how far forward load carriers have to be positioned.
11. To improve the vertical positioning of the load carriers a system using mirrors and a bright coloured line should be used that indicates how far forward load carriers have to be positioned.
12. To improve the vertical positioning of the load carriers a system with a stopping edge/barrier should be used.

5.4.3 Cross-docking flow

To determine the strategy for the cross-docking flow, the decision tree starts with the question of whether automation for that flow is worthwhile. The other paths of the decision tree also do this in variations of this question. The reason for this is that automation should have big advantages over the existing situation and the investment in the automation project should have a reasonable payback period. If this is not the case because for example the quantities of products moved in this flow is very low, automation would not be cost-efficient.

The decision tree continues with questions for determining whether should be opted for an automatic truck unloading system (ATUS) (5) or manual unloading (6). This depends on the factors whether the incoming goods are internal flows and whether the budget of the project is sufficient. When the result of the question is an ATUS, the decision tree proceeds to the question whether a system could be made that communicates the ordering and destinations of the load carriers in the arriving trucks to the warehouse management system before the arrival of the trucks. Besides, the business case for such a system should be positive. If so, such a system (8) enables for immediate picking up of the load carriers by the AGVs after unloading by the ATUS. If not, a system should be developed that enables operators to scan barcodes attached to the incoming load carriers to communicate to the warehouse management system what the ordering of the load carriers is (9) to enable picking up of the load carriers by the AGVs. After this step, the strategy is determined.

If the outcome of earlier questions in the decision tree would not be an ATUS (5) but manual unloading (6), the decision tree progresses differently. The option of unloading incoming load carriers of trucks manually by operators that use an electric pallet truck or similar device results in the need for usage of a barcodes system and a lanes system. A barcodes system should be developed that enables operators to scan barcodes that are attached to the incoming load carriers to notify the warehouse management system of the arrival of a load carrier. In this system, the warehouse management system should then notify the operator in what lane he has to place the load carrier. In this system of lanes, the operator has to place the load carrier into the lanes manually, barcodes have to be positioned in the neighbourhood of the corresponding lanes that enable the operator to communicate the placement of a load carrier in the lane by scanning the barcode.

A lanes system should be developed to place the load carriers in. Each lane should have guiding rails that prevent horizontal displacement of the load carriers. To improve the vertical placement of load carriers in the lanes a lane positioning tool should be chosen. This is the next question in the decision tree. For this, there are three options. Markers on the guiding rails (10), a system with a mirror and bright coloured line (11), or a stopping edge/barrier (12). More detailed descriptions of these options can be found in Section 4.2.6. The choice for this should depend on three factors. The first is the budget for the project. A system with a stopping edge that can retract would be more expensive than a system with markers. The second is the type of load carriers used. For example, a pallet is less prone for bumping out of its place than a role container is. The third is future experiences with the options. Currently, we have not enough experience of what option would be most effective in different situations. This knowledge is expected to be learned in the future. Because of these three reasons we provide a list of options in the strategy instead of one solution.

5.4.4 Storage flow

The storage flow starts off with the same type of first question for the same reason as the cross-docking flow. However, in the strategy, we distinguished between automating the entire storage flow, no automation, or only from a later point in the process. The choice of automation we have here is between automating from the inbound truck dock or from when the load carriers exit the storage area. This is the situation we observed at the distribution centre in Chapter 3. Automating from the inbound truck dock would result in that AGVs would transport the load carriers from the inbound truck dock to the storage area, would drop off the load carriers in the storage area, and facilitate the picking up and transport of the load carriers between the storage area, the marshalling area, and the outbound truck docks. Automating from when the load carriers exit the storage area would only result in the AGVs facilitating the transport of the load carriers between the storage area, the marshalling area, and the outbound truck docks. The choice between these alternatives and the choice of not automating should be made on the question of what degree of automation is the most cost-efficient and the degree of automation of other flows in the warehouse. For example, we observed that in the distribution centre we observed in Chapter 3 the storage area was too small to justify automation from the inbound truck docks. However, the transport of the load carriers away from the storage area could be automated. This, also because AGVs would be used to transport load carriers from other flows.

Theoretically, an additional point option in the storage process flow to automate from exists. This is the point from the entrance into the storage area. However, we decided to not include this in Figure 5.1 and the general strategy. This because the complexity of strategy would increase significantly and we did not want to make the decision tree too complex. Automation from the entrance of the storage area would lead to additional questions as to how to transport load carriers from the inbound truck dock to the entrance of the storage area. Also, a question would be how to automate the storage area. Do this using AGVs or another type of automated system. These topics we did not study during this project because the main scope is on the identification of incoming products and therefore we also decided to exclude this. However, we do want to mention this additional option.

Focussing back on the decision tree, If the decision is made to automate from leaving the storage area, a similar lanes and barcodes system should be used for the manual positioning of the load carriers as described in Section 5.4.3 of the cross-docking flow (4). The decision tree progresses from this point in the same way as the cross-docking. Also here the choice between what lane positioning tool to be used has to be decided.

If the decision is made to automate from the inbound truck dock, the decision tree also progresses the same as cross-docking flow with the same related choices. The only difference to the cross-docking flow is that the load carriers are transported to a storage area.

As the last note for this section, in Section 4.2.5 we stated that using rows or racks are both solutions to store load carriers. However, choosing between these does not depend on the identification strategy. Therefore we did not incorporate these solutions into the strategy or the decision tree.

5.4.5 Order picking flow

The order picking flow also starts off with a question about whether automating is worthwhile. Here, we distinguish between automating before the order picking process and after the process. This, because the order picking process used varies significantly between different warehouses of clients. The one warehouse could have a fully automated order picking process. Meanwhile, in the other warehouse products could still be picked by hand. These different situations allow for different implementation possibilities by AGVs. Therefore, the first decision that has to be made is whether the transport of load carriers from the inbound truck dock to the order picking area/process has to be automated by AGVs. It could be that automation by AGVs is not cost-efficient for this flow because the quantity of goods moved is too small. It could also be the case that automation by other automatic systems would be more suited. This we observed in the distribution centre we studied in Chapter 3. Both these reasons result in the decision to not automate this part of flow with AGVs and the decision tree progresses to the question whether the transportation of load carriers after the order picking should be automated by AGVs.

If the transportation of the incoming load carriers should be automated by AGVS the decision tree progresses in two ways. One path leads to the decision of how this automation should be achieved. This part of the flow we discussed earlier. Therefore, we will not elaborate more on this path. The other path in the decision tree progresses to the same question if the automation by AGVs would not be worthwhile. Namely, whether the transportation of load carriers after the order picking should be automated by AGVs.

When the transportation of load carriers after the order picking process to the outbound should not be automated by AGVs, the decision tree stops. Otherwise, a new question pops up whether the output of the order picking process is mechanical standardised. This, we observed at the distribution centre of Chapter 3. When this is the case, load carriers are suited properly to be picked up by AGVs. If this is not the case, a solution should be selected to standardise the positioning to enable AGV usage. Then the decision tree progresses to the usage of manual positioning and a barcodes system. Again, as we discussed in earlier flows a lane positioning tool should be chosen.

5.4.6 Validation of our solution

Validating our generalised strategy solution is not straightforward because of the timeframe of this project and due to the fact that our decision tree model is a theoretic model. Within 10 weeks we cannot implement and evaluate our solution into practice. Besides, not being able to visit other logistical companies negatively influenced our capability to validate our results. However, we did test our decision tree model on the project at the distribution centre we studied in the case study. This test was positive because we were able to apply our decision tree model on the project and select an appropriate identification strategy.

To check whether relations with solutions and conclusion in our model are in theory legitimate we also consulted with a staff member of TMH. This staff member was/is an expert in the field of automation and logistics. He concluded that the claims we made are logical and he only had some minor remarks. We used this feedback to improve our model.

5.5 Summary

In this chapter, we presented how we created a generalised strategy for identification. In Section 5.1, we described the decision process. The procedure used consisted of five steps. We stated how the management of TMH was introduced to the different solutions available and how the decisions were made. We conclude that the criterion investment costs is the most important criterion followed by reliability criteria for deciding what solutions to use. Next in Section 5.1, we generalised the logistical environment. We concluded that the variety of activities TMH could encounter can be summarised into cross-docking, storing products, and order picking. We determined what opportunities there are for TMH in such situations. Thereafter in Section 5.3, we presented what set of solutions have a place in the generalised strategy. The reasoning of why choices have been made was explained. Lastly, we presented in Section 5.4 our generalised strategy for identification. We illustrated the strategy with a decision tree model. We explained how the model works, what considerations we made, and how TMH could use our model. We describe how we validated our decision tree model. We tested our strategy on the case study project and consulted with an expert in the sector of automation and logistics.

6 Conclusion, discussion and recommendations

In this chapter, we will discuss and conclude about the generalised strategy for identification in logistical settings we created. We will conclude about the findings of our research and express our personal opinion on them. Next to that, we will present a critical discussion on the limitations of our bachelor thesis. Lastly, we will give recommendations on how to use the strategy we created and other topics of interest for future projects. This chapter is structured as follows:

- Section 6.1 concludes about the research
- Section 6.2 discusses the limitations of our research
- Section 6.3 states our recommendations to Toyota Material Handling

6.1 Conclusion

To improve the ability to implement AGV systems in a logistical environment, we created a generalised strategy for identification of incoming goods in a logistical environment. To achieve this, we set ourselves a total of four research objectives that we will conclude about in this section.

Our first objective was to familiarise ourselves with the topic of AGVs and what is needed for the implementing of AGV systems. The most important conclusion we drew from this is that we had to define what identification is. We did this by stating that identification is three things: *Knowing where to pick-up, what load of goods and where to deliver that load of goods.*

The second objective was to perform a case study to learn about an AGV implementation project at a DC and particularly focussing on how the identification process takes places at that facility. We learned how identification was happening and concluded that the main issue related to identification was the exact location of load carriers that needed to be picked up by AGVs. A distinction we noticed was the difference between whether the load carriers were positioned mechanically or manually by staff. We concluded that this could be a key area where improvement could be made.

Next, we had the objective to study how the identification process could be changed. We concluded that the identification process could be separated into different phases to have a systematic approach to how the identification process could be changed. In the end, we produced an overview of solutions available with 19 different possibilities to shape the identification process. Providing this insight into how the identification process could be changed is already valuable in our opinion.

The last objective was to create a generalised identification strategy based on our already completed work. We selected criteria to support the choice of what solutions should be part of the generalised strategy. We concluded that the criterion investment costs is the most important criterion followed by the criteria of reliability, consistency and quality-related. To make the strategy, we first had to determine what situations should be included in the strategy. We concluded that the activities performed in the logistical environment can be summarised into cross-docking, storing products, and order picking. Based on all these previous conclusions, we created a theoretic decision tree model that illustrates our generalised identification strategy. The decision tree model provides good support to help to pick the solutions to be used in the identification process during new projects.

Taking the findings of our study into the broader applicability than TMH, companies in the AGV industry could benefit from understanding the concept of identification related to AGVs. Understanding what is going wrong with solutions in current AGV implementation projects in terms of the concept of identification by AGVs is key in the search for solutions. How to discover other solutions to the experienced AGV related problem as a business can be done in different ways. However, we experienced that splitting up the process in phases increases the ability to look thoroughly into the problem.

6.2 Discussion

In this section, we look critically at our research and discuss the limitations of our work. Topics we discuss are the link with practice, the influence of our case study, the strictness of our decision tree model, and the decision process on selecting criteria.

At the start of this research, the plan was to combine a theoretical approach with experiences from practice experiences at logistical companies including observations, interviews to find solutions for our problem. However, due to the global pandemic of Covid-19, our fieldwork at logistical companies was severely limited and we mainly had to work at home. This impacted the research negatively because we could not verify whether theoretical solutions would work in practice, although the time available time of 10 weeks was also a factor in this. Also, other possible solutions from practice could not be acquired since we could only visit very few logistical settings. Another consequence from this was that our communication and feedback with the staff of TMH about the research was limited. This all resulted in the research being more theoretical than we would have wanted and it is linked not as much to practice as we would have liked initially. We would have liked to visit more logistical companies and to gather more knowledge to be able to learn more about the procedures and solutions at those companies. This would have resulted in more generic applicable results conclusions in this project we think. Also, we maybe could have validated our results and conclusions more with more experiences from practice.

Another limitation of our research is that the case study of a DC we performed strongly influenced our research. On the one hand, this is positive because the case study yielded a lot of insights into the processes and the problems. However, on the other hand, executing the case study caused that in the subsequent phases of our research we still had the situation of the case study in mind and adapted on this. The broader picture was influenced by making sure solutions and in the end, the generalised strategy would fit in our experiences of the case study. In combination with that the visits to other logistical companies were severely limited, as mentioned earlier, the eventual overview of solutions available and the decision tree model could be too specific to our experiences at the case study and not always be applicable in all other situations that could be encountered.

One more limitation is that we presented the final deliverable, the decision tree model, as the strategy that should be followed. However, the argument can be made that the model is too theoretical and the decisions in practice are not as strict as we state here.

The last limitation is that the decision process about what criteria to use could be more supported or validated. We identified themes of criteria but we excluded specific criteria or combined criteria. However, some criteria do still have overlap. An argument can be made to combine more criteria.

6.3 Recommendations

In this section, we present our recommendations for organisational implementation of our research. We also suggest what would be topics of interest for further research.

6.3.1 Possibilities for organisational implementation

We recommend TMH to use the decision tree model strategy we created as a tool in future projects in logistical environments and only deviate from the strategy when there are very convincing reasons for this. The decision tree model gives good guidance to help to select the solutions that can be used best.

The goal of this research was to create a theoretic strategy model. We recommend TMH to start using the model in practice and experience how the theoretic strategy works in reality. We suggest TMH to change the model in the future when our theoretic model does not match with new situations/activities encountered in practice. When an encountered activity would not match with one of the functions of cross-docking, storage or order picking, we advise to add this activity into the model and select adequate accompanying solutions for the situation.

Also, TMH could alter the applied solutions in the strategy in the future when the suggested theoretic solutions do not work as well in practice as intended. When this would be the case, TMH should choose another solution that would work better and change the related conclusions in the decision tree model.

Next, we suggest that the decision tree model in the future should be adapted to innovations in the logistical sector. For example, AGVs improve over the years and these improvements could affect what identification strategy is best.

We recommend TMH to make use of the knowledge on gained on all the solutions that are available for changing the identification process. The goal of this research was to improve the identification process, and a large part of this improvement is giving insight into how the process can be changed to what TMH is doing today.

6.3.2 Further research

For future research, we suggest looking into how the strategy can be improved and check how the strategy would be working in reality. During this research, we were not able to conclude on every solution what would work best. An example of this is the tool that best can be used for positioning load carriers in lanes with guiding rails. Besides, due to the timeframe of this project we were not able to verify how the created strategy works in practice. We recommend looking into this topic.

Another suggestion is to look into ultrasonic and ultra-wideband technology for locating and tracking load carriers. These are both localisation technologies comparable to RFID tags but have higher accuracy. Possibly, ultrasonic or ultra-wideband technology could be used to determine the positioning of load carriers by AGVs, this could enable the AGVs to pick up the load carriers without staff positioning the load carriers at a precise predetermined location. The reason that we did not incorporate these technologies into our research is that we came across these technologies in a too late stage of our research.

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Appendix A: Cleaned up list of problems

Problem statement: The ability to implement AGV systems in a logistic setting by the department of Logistics Automation at TMH is insufficient and should become sufficient.

TMH has currently not enough knowledge on how to properly implement AGV systems in a logistical setting without many problems. At the moment, they have a few projects in logistics but they are characterised by problems that do not occur in a production setting. There are more requirements for the implementation of AGVs in a logistical setting but TMH does not have the knowledge what these requirements and its associated solutions are.

List of problems with a further explanation if needed:

- **Sticking out load: the load transported is wider than the AGV =** This refers to problems with so-called non-conveyable items. Items that are too big or have such unusual dimensions that they stick out from the load carrier they are on. This creates the problem that the AGV could hit other objects because it does not know that it transports sticking out objects or by how much the objects stick out.
- **Problems with the load carriers =** Load carriers, mainly the pallet the goods are on, could have problems with them. These problems range from not having all the same kind of load carriers to broken load carriers.
- **Identification problems =** To transport goods by an AGV, the system needs to know three things. The current location of the goods, the location the goods have to be moved to and what the goods are. This is called identified. This information is not always known what makes complete automation not possible.
- ***Flows of goods are not previously identified* =** New goods, this can be pallets, containers, carts or other items coming into the system from earlier logistic processes are not previously identified.
- **Load reflection problems =** AGV cannot identify loads due to reflection of the load. An AGV uses lasers to identify loads. These lasers could be reflected by the load which results in an error.
- **Plastic shields of fork holes =** Goods on pallets are usually covered with plastic for protection. However, this plastic can also be in front of the fork holes of the pallet. If this happens the AGV can no longer locate the fork hole.
- **Defective load carriers =** A load carrier can be broken or brake during the process. This gives problems ranging from that an AGV cannot pick up that load carrier to severely damaging the goods on that load carrier because the AGV does not register that the load carrier is broken.
- **AGVs cannot locate the load**
- **Humans do not place goods in the correct position or order**
- **Standardisation problems**
- **Pallets are not the same**
- **Problems in navigation =** An AGV uses lasers to measure its location to navigate itself. Problems can occur in this process.
- **AGVs cannot identify the "Reflectors" =** AGVs uses reflectors that are on walls and pillars to navigate itself. It constantly sends laser beams around itself. When a beam gets reflected and comes back to the AGV this information gets processed to determine its location. For this determination, 3 different reflectors are needed. If an AGV cannot identify enough reflectors this yields navigation errors.

- **Problems with behaviour customer =** Due to the behaviour of the customer, either the management decisions or actions of the staff directly working with the AGVs, problems occur on making the AGVs work properly.
- **Never-ending new demands by customer =** The management of the customer comes up again and again with new demands on how the AGV system should work. Or the layout of objects where the AGVs operate changes. These changes require constant adapting from TMH what does always work well.
- **Humans do manual overwrites =** Most AGVs of TMH can be controlled manually. However, if this happens the warehouse management system does not have the correct information on where goods are anymore because when manually moving goods this movement is not registered automatically in the warehouse management system.
- **Humans do not follow "the rules" =** For AGVs to work properly, humans have to follow certain rules. For example, there should be no lying around objects blocking paths of the AGVs or goods to be moved should be placed at a certain position with high precision.
- **Employees do not "accept" the AGVs =** AGV systems work together with employees and not on its own. They are dependent on the correct actions of employees. Examples are known that employees deliberately hinder AGVs or brake AGVs because they see them as competition for their job.
- Problems with location-specific requirements
- **Setup/detailed problems =** Every client of TMH is different. This results in client-specific problems that usually take a long time to fix.
- **Problems in wireless communication =** AGVs use wireless communication to communicate with the controlling system. Problems occur in this communication when the Wi-Fi system is not good enough.
- **Communication gets jammed =** Environment where AGVs are operating in, usually have a lot of other machines, other signals and metal around them. These factors can result in jamming the communication of AGVs with the controlling systems.
- **Problems with floor requirements**
- **Floor not flat**
- **AGVs are waiting a lot**
- **Congestion of AGV traffic**
- **Task manager not optimal =** The task manager is the system that decides what job will be executed by what individual AGV. This task manager's decision is not always the optimal decision.

Appendix B: Usage of radio-frequency identification

Information on the phases we refer to in this Appendix can be found in Section 4.1.

A concept that is getting more and more integrated into warehousing is the usage of radio-frequency identification (RFID). It is a non-contact automatic identification technology that can identify objects and relevant data through radio signals automatically. Advantages are high storage capacity, high reliability, storage information exchange, etc. (Pang et al., 2019). The process of recognition does not require human involvement and the requirements on the working environment are low (Chen & Zhao, 2018).

In a warehouse, a RFID tag enables real-time tracking of products. The exact location in the warehouse would be known at any time. The RFID tag transmits a signal containing in what rack and height it is located within the warehouse. This could be a good solution for the identification problem for AGVs. When a RFID tag would be linked to a load carrier, the AGV will know the load carrier's location. This in combination with that the warehouse management system is provided with the information about what load of products is linked to the RFID tag and the destination of this load of products is determined, the identification would be in theory successful.

There is a difference between active and passive RFID tags. Active RFID tags have a built-in power source and can broadcast signals by themselves. Passive RFID tags do not have a built-in power source and can only broadcast a signal back to a reader. The costs of passive RFID tags is significantly lower compared to active RFID tags. So is the range of the signal of the tags. For our intended application we will need active RFID tags.

On entering a facility, an incoming load carrier could already be linked to a RFID tag. This would make scanning and using a barcode redundant when the load carrier is entering the facility. The RFID tag would provide information about what is on the load carrier. The problem with this is that for using RFID tags that are already linked to load carriers on entering a facility is that those load carriers should originate from internal flows. Practically, it is not possible to achieve the linking if load carriers would come in from another organisation.

A disadvantage of using RFID tags would be if the RFID tags would not be linked to the load carriers on entering the facility. Then the linking would have to take place in the checking phase to make use of RFID in later phases of the process. A barcode that is attached to a load carrier should be scanned and the RFID tag has to be attached to the load carrier to link the load carrier and the RFID tag. The linking of the RFID tags would create additional work in the checking phase but from this could be benefited in later phases in the process.

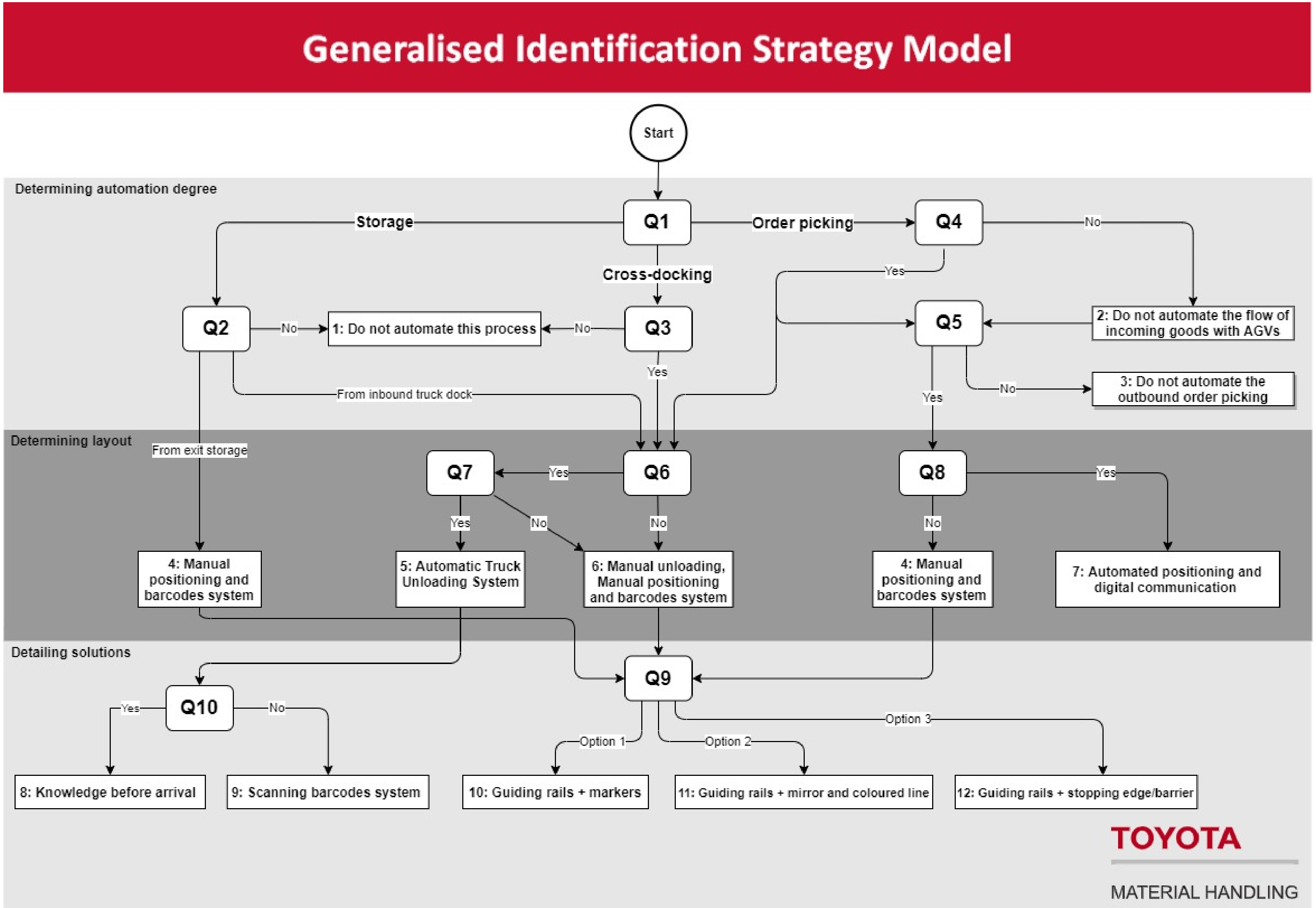
There is a problem with the usage of RFID tags when load carriers would leave a warehouse. The RFID tags would have to be detached from the load carriers or the carrier-pallets containing the RFID tags should have to be removed. This is needed because the RFID tags have to be re-used. This would create a significant amount of additional work in the warehouse.

By using RFID, tracking during the storage and placement phases would be automated. When a RFID tag is linked to a load carrier, the warehouse management system automatically tracks the load carrier. This makes the steps of scanning barcodes on the load carriers and at the storage position redundant.

In the placement phase, Incorrect positioning and bumping could be solved by the usage of RFID tags. When a load carrier would be positioned to be picked up by AGVs, RFID tags constantly broadcast their position. The warehouse management system could receive this position and pass-through this information to the AGV system. The AGVs would get notified of the position of the load carrier and could pick it up. The advantage is that no precise placement of the load carrier would be needed by the staff in the warehouse because the position of the load carrier is passed through to the AGV anyways. However, we recommend using this RFID solution in combination with the lanes with guiding rails. This, because the guiding rails are an easy solution to horizontal displacement of load carriers and prevent skewed positioning of load carriers.

A potential problem for the implementation of RFID tags in the placement phase would be precision. For AGVs to pick up a pallet, the precise position of this pallet has to be known. At this point, it is unknown how precise the location of a pallet could be determined. Two years ago, according to Chawla et al. (2018), the average accuracy was as low as 15 centimetres. Undoubtingly, technology will have progressed in the 2 years until now but 15 centimetres accuracy is insufficient. Namely, AGVs require a minimum accuracy of 7.5 centimetres. At this point in time, it is also unknown how the exchange between the signal of the RFID tag and the AGV itself workout. The AGV uses a special camera and lasers to localise a load carrier. Adaptation of software would be needed and it is unknown whether this combination would work.

Appendix C: Compact overview of generalised identification strategy model



Complete list of questions referred to in the decision tree model:

Determining the automation degree

Q1 = What function does the flow to be automated within the logistical setting of the client perform?

Q2 = Is the business case positive to automate from a certain point in the storage process for the client with AGVs?

Q3 = Is the business case positive to automate the transportation of load carriers in the cross-docking process of the client with AGVs?

Q4 = Is the business case positive to automate the transportation of the incoming products to the order picking area by AGVs?

Q5 = Is the business case positive to automate the transportation of load carriers after order picking to the marshalling area and/or outbound truck docks?

Determining the layouts

Q6 = Are the products arriving at the inbound truck dock(s) an internal flow?

Q7 = Is the budget of the project sufficient for automatic truck unloading systems solutions?

Q8 = Is the arrival of load carriers from order picking process automated?

Detailing the solutions

Q9 = What lane positioning tool best suits the project?

Q10 = Is it achievable to acquire the information on the ordering and destinations of the load carriers inside the truck before the arrival of the truck and is the business case for this measure positive?

Complete list of conclusions referred to in the decision tree model:

1. Automation of this activity by AGVs should not be conducted.
2. The transportation of load carriers from the inbound truck dock to the order picking area/process should not be automated by AGVs.
3. The transportation of load carriers after the order picking activities should be automated by AGVs.
4. The solution applied to position load carriers for AGV transport should be a manual positioning system. A system of lanes with guiding rails should be developed. This system should allow for manual placement of load carriers by operators. To determine what products are on a load carrier, in what lane a load carrier has to go and to notify the warehouse management system of the placement of load carrier a barcodes system should be used.
5. To unload load carriers from trucks at the inbound truck docks automatic truck unloading systems should be used.
6. Unloading of the load carriers from trucks at the inbound truck docks should be conducted manually by operators. The solution applied to position load carriers for AGV

transport should be a manual positioning system. A system of lanes with guiding rails should be developed. This system should allow for manual placement of load carriers by operators. To determine what products are on a load carrier, in what lane a load carrier has to go and to notify the warehouse management system of the placement of load carrier a barcodes system should be used.

7. The positioning of the arrival of load carriers is automated and so completely standardised. This should be used to inform the AGV system of the positioning of load carriers to be moved by the AGV system. The information on where a load carrier has to go and when a load carrier is ready to be picked up should be digitally communicated by the automated system from the order picking process to the AGV system.

8. A system should be made/designed that acquires the information on the ordering and destinations of the load carriers inside a truck before the arrival of a truck. This will allows for immediate picking up of load carriers by the AGVs after they are unloaded by an automatic truck unloading system.

9. A system should be developed that enables operators to scan barcodes attached to the incoming load carriers to communicate to the warehouse management system what the ordering of the load carriers is. This will allows for immediate picking up of load carriers by the AGVs after they are unloaded by an automatic truck unloading system.

10. To improve the vertical positioning of the load carriers markers should be made on the guiding rails that indicate how far forward load carriers have to be positioned.

11. To improve the vertical positioning of the load carriers a system using mirrors and a bright coloured line should be used that indicates how far forward load carriers have to be positioned.

12. To improve the vertical positioning of the load carriers a system with a stopping edge/barrier should be used.