CHALMERS
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Automated Deliverance of Goods by an Automated Guided Vehicle

Case study of the testing and implementation of an AGV within the production at Volvo Group AB, Tuve Gothenburg

Bachelor Thesis - Mechanical Engineering

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Abstract

The global automotive industry presents a highly competitive business environment. Corporations are constantly trying to adapt to changing market demands. Throughout all industries companies are rapidly readjusting their operations in line with the fourth industrial revolution. It has been named Industry 4.0 which encompasses a wide range of new key enabling technologies surrounding a renewed digitization of the manufacturing environment for industries worldwide. In sight of this, Volvo Trucks in Tuve is exploring a variety of possibilities for implementing new autonomous solutions within their production. They are doing so to increase their production efficiency and to further advance their position on the global market.

This study aims at setting up a safe and efficient process where an automated guided vehicle (AGV) is used to deliver material from one assembly process to another. The study was carried out at Volvo Tuve assembly plant in Gothenburg during the first two quarters of 2019. The main questions asked were if an implementation of the process was possible within the given time frame and how the workflow needed to be designed in order to achieve a safe work environment. This study was also set out to describe how the level of automation within the internal material handling could be increased.

Several methods were used in order to gain valid results that could lead to a solid conclusion. Different kinds of interviews where held with employees at Volvo Tuve alongside thorough observations which both functioned as a foundation for the design of a new workflow. A large focus were place on providing the authors with the skills necessary to program the AGV to perform desired tasks.

Analysis of tests run both in Pilot Plant and in the assembly process showed several key findings. The results contained solutions regarding the docking procedure between the AGV and the used trolley. These findings showed that the docking procedure presented major hurdles which stagnated the development of a robust workflow. One solution to this was to mount different fixtures in the floor to enable a more reliable docking process. Another solution which came at the very end of the study showed that the docking procedure could greatly be improved by changing certain parameters in the settings for the AGV.
One other important result came through the risk analysis which provided information that were used in programming the AGV to suit the given demands. When one type of programming had been selected, the AGV went through three capability tests during production in the factory. These showed that the designed workflow did not meet the standards for new tooling and equipment.

Based on these results, the authors concluded that an automated delivery of material by an AGV at the given station could not be implemented within the given time frame. Several recommendations were made in order to succeed with this implementation. One recommendation was to request a few software updates for the AGV that would elevate its capabilities. Another one was to design clear rules for the workflows surrounding the AGV.

Sammanfattning

Den globala fordonsindustrin presenterar en mycket konkurrenskraftig affärsmiljö. Företag försöker hela tiden anpassa sig till förändrade marknadskrav. Inom alla branscher justerar företagen snabbt sina verksamheter i riktlinje med den fjärde industriella revolutionen. Den kallas för Industry 4.0 och omfattar ett brett utbud av nya teknologier kring en digitalisering av tillverkningsmiljön för industrier världen över. Volvo Trucks i Tuve undersöker olika möjligheter för att implementera nya autonoma lösningar inom sina produktionsflöden. Detta görs för att de ska öka sin produktionseffektivitet och för att ytterligare avancera sin position på den globala marknaden.

Denna studie har målet att designa en säker och effektiv process där ett automatiserat styrt fordon, så kallad AGV, används för att leverera material från en monteringsstation till en annan. Undersökningen genomfördes vid Volvo Tuves monteringsanläggning i Göteborg under de första två kvartalen år 2019. De viktigaste frågorna var om ett genomförande av processen var möjlig inom den angivna tidsramen och hur arbetsflödet skulle utformas för att uppnå en säker arbetsmiljö. Denna studie siktade också på att beskriva hur automationsnivån inom den interna materialhanteringen skulle kunna utvidgas.

Flera metoder användes för att nå användbara resultat vilket kunde leda till en stabil slutsats. Olika typer av intervjuer hölls med anställda på Volvo Tuve och noggranna observationer genomfördes. Dessa båda metoder fungerade som grund för att utforma ett nytt arbetsflöde. Ett stort fokus låg på att ge författarna till studien den kompetens som krävdes för att programmera AGV:n till att utföra önskade uppgifter.

Analys av tester genomförda både i Pilot Plant och i det faktiska monteringsflödet visades flera viktiga resultat. Resultaten innehöll lösningar angående dockningsförfarandet mellan AGV:n och den använda vagnen. Dessa fynd visade att dockningsförfarandet presenterade stora hinder som stagnerade utvecklingen av ett robust arbetsflöde. En lösning på detta var att montera olika armaturer i golvet för att möjliggöra en mer tillförlitlig dockningsprocess. En annan lösning som kom i slutet av studien visade att dockningsförfarandet i hög grad kunde förbättras genom att ändra vissa parametrar i inställningarna för AGV:n.
Ett annat viktigt resultat kom till följd av riskanalysen som tillhandahöll information som användes vid programmering av AGV:n för att möta de givna kraven. När en typ av programmering hade valts genomgick AGV:n tre kapacitetsprov i produktionen på fabriken. Dessa visade att det utformade arbetsflödet inte uppfyllde kraven för nya verktyg och ny utrustning.

Baserat på dessa resultat drog författarna slutsatsen att en automatiserad leverans av material av en AGV vid den givna stationen inte kunde genomföras inom den angivna tidsramen. Flera rekommendationer gjordes dock för att lyckas med denna implementering. En rekommendation var att begära några mjukvaruuppdateringar för AGV:n som skulle höja dess duglighet. En annan var att utforma tydliga regler för arbetsflöden runtomkring AGV:n.

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Gothenburg, June 14, 2019

Abbreviations

IoT - Internet of Things
LoA - Level of Automation
AGV - Automated Guided Vehicle
SICK - German company who manufactures intelligent sensors
PLC - Programmable Logic Controller
AGC - Automated Guided Car
HTA - Hierarchical Task Analysis
VR - Virtual Reality
RQ - Research Question
AI - Artificial intelligence
SLAM - Simultaneous Localization and Mapping
I/O - Input/output

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1 Introduction

Chapter one provides an opening introduction of the study. The purpose of this first chapter is to present the reader with an initial background alongside the aim and limitations of the thesis.

1.1 Background

Volvo Trucks has continuously been working on automating different parts of their manufacturing processes. In recent years they have been considering and testing certain automated solutions to handle parts of their internal logistics within their production plant located in Tuve, Sweden. A few processes have already been automated but as they describe it, there are many more steps to take towards their goal of fully incorporated autonomy solutions throughout their factory.

Automated guided vehicles, so-called AGVs, are being used at a few certain locations and routs throughout the factory with the purpose of delivering material and goods both from their inventory and from their pre-assembly lines to their main manufacturing line, where the trucks are assembled. All other transportation of goods and material are currently being handled by operators using different kinds of forklifts. Some of them are attached with several trolleys, so-called tug-trains which are shown later in figure 2.4.
These transportation routes are carried out a certain number of times per shift. This way of working hinders the principle of delivering just in time and it crowds narrow passages throughout the factory. Another problem with the current way of handling the deliverance of goods and material seen from a business standpoint is the fact of operating costs for manual labor. Cutting costs in a competitive business environment is key for growth and expansion.

Volvo Group's future ambition regarding their logistics handling is therefore to explore the implementation of a larger number of AGVs within their production processes. This to increase their automated workflow resulting in an increased operating efficiency and flexibility.
The current AGVs are using magnet strips to navigate which are placed in the floor. This causes problems whenever there is a need to switch routes. In order to advance their production development Volvo wants to use a different type of AGV. Volvo has bought two AGVs of model MiR200 which have gone through initial hardware tests in a past bachelor thesis. This model is be able to navigate and perform tasks in a

safe way without the use of magnetic strips planted in the floor. This new model of AGV creates a map of the factory which it uses to navigate and orient itself with the help of built in sensors and cameras.

In the future, these AGVs are to collaborate amongst themselves and their environment while carrying out several autonomous missions and tasks throughout the production wherever there is a demand. This should lead to an increased effectivity and saved operating costs.

1.2 Aim

This study was aimed at setting up a safe and efficient process where an automated guided vehicle was used to deliver material from one assembly process to another. This is done by evaluating the different possibilities of successfully implementing an AGV of type MiR200 within a specific area of the main production in Volvo Trucks' factory in Tuve, Sweden.
The AGV was supposed to operate between the pre-assembly line where gearbox beams were assembled and the main manufacturing line where the trucks finally were assembled. The idea with these new types of AGVs was to program them to deliver required material when needed without any guidance of magnetic stripes or guidelines planted in the floor.
The new process and equipment was to be evaluated in the Volvo Pilot Plant in Gothenburg and later tested in the assembly process in the Tuve assembly plant. When this was done, the differences, advantages and savings between having an AGV were to be evaluated and compared with the current work flow which is carried out manually by operators.
The following questions are to be answered:

- Is it possible to get the given AGV to work as desired in production at this point?
- How can the level of automation within the internal material handling be increased?
- How is an AGV centered workflow designed in a safe way?
- What are the benefits of AGV automation compared to older and manually operated workflows?

In order to achieve this aim the procedure described in the methodology section will be followed.

1.3 Limitations

The deadline for the thesis is set to mid-June 2019. This project will not focus on the following aspects due to time limitations and to match the scope of 15 Swedish university credits:

- The report will only assess the operations regarding the AGV's function to pick up a trolley with a pre-assembled gearbox beam, deliver it to the production line and pick up an empty trolley and bring it back to the pre-assembly area.

- This project will only focus on implementing one AGV to execute a specified task. Integrating more AGVs is a future project.
- The AGV will not be connected to Volvo's other internal production systems within the factory. It will only be connected to the pickup and delivery stations for this specific case.
- Testing of the AGV will only be held in Volvo Pilot Plant and within a limited area of the real production line. These tests in Pilot Pland will not include mounted fixtures in the floor and other characteristics that are to be taken into consideration out in the real production.
- The project will only include programming the tasks the MiR is supposed to complete.
- The AGV will only be able to pick up one specific type of trolley and no other.
- The trolleys being used are already designed and the general structure will not be changed except miner attachments and incremental detail changes.
- The MiR will only carry one trolley at the time.
- Direct modification of the AGVs hardware and internal software will not be made. Nor will any detailed description be given of how its internal electronics and top module are functioning.

1.4 Specification of issue under investigation

The core objective of this report is to answer questions regarding the possibilities of implementing an AGV of the type MiR200 to complete desired task in a safe and autonomous way. To accomplish this goal, it is critical to state what kind of traffic is needed to be applied in the areas where the AGVs are to operate and to eliminate the risk of collision between the AGV and human operators.

2
Theoretical framework

Chapter two will consist of a the theoretical framework for the thesis alongside a company description.

2.1 Company description

AB Volvo is a multinational automotive manufacturer founded in Sweden 1926. The company's branches of manufacturing are production of heavy-duty trucks, construction equipment, buses, financial services alongside marine and industrial drive systems. Their main focus is the production, distributions and sales of trucks where they in 2017 were placed second in the list of heavy-duty trucks manufacturers. [Volvo Group, 2018].

Volvo was founded by Assar Gabrielsson and Gustav Larsson as an affiliated company of SKF with an initial plan to construct a special set of bearings designed for the American automotive industry. This plan was soon to be discontinued and the company shifted its focus towards manufacturing cars designed to withstand the Nordic climate. The company started their car production at the end of 1926 in their factory in Gothenburg Sweden, located close to their current headquarters. In the following years Volvo ramped up their production and launched their first truck, the "Series 1" which became an immediate success.
Volvo went public in 1935 on the Stockholm Stock exchange and SKF thereby sold all their holding shares in the company. In the following decades Volvo launched several new products such as buses and acquired several companies along the way. One of them was Pentaverken AB which had been manufacturing engines for Volvo. They had also been providing engines for the marine market. [Volvo Group]

In 1999 Volvo Group sold Volvo Cars to Ford Motor company for 6.5 billion dollars and refocused their manufacturing to the division of heavy-duty vehicles. Currently Volvo's brand portfolio consists of Volvo, Volvo Penta, Terex Trucks, UD Trucks, Renault Trucks, Prevost, Nova Bus, Mack and Arquus alongside joined ventures with various brands in Asia.

2.1.1 Volvo today

Volvo Group's current headquarter is located in Gothenburg Sweden and employs around 100 thousand workers worldwide with a workforce divided globally as shown in figure 2.1. Production facilities are held in 18 countries with product sales in 190 markets. Europe is the biggest market holder which sums up 41% of the total net sales worldwide. Production of trucks, buses, engines and construction equipment are held worldwide and twenty of these facilities are located in Europe, primary in Sweden, Belgium, France and Poland.

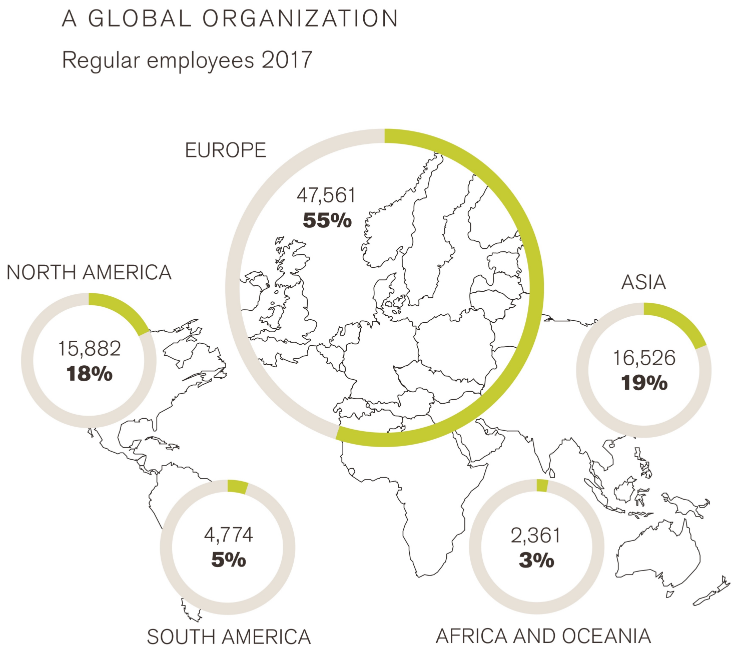

Figure 2.1: Employee Global Chart [Volvo Group, 2017]

2018 was a record setting year for Volvo where they recorded net sales of SEK 391 billion with an improved adjusting operating income of SEK 40.7 billion where the corresponding operating margin was ten percent. The sale of vehicles stood for 77% of the net sales in 2018 while services stood for 20% and financial services for the remaining 3%. The vehicles sales came from a total delivery of 226,500 trucks, 82,600 units worth of construction equipment, 8,400 buses and 48,500 engines from Volvo Penta. Volvo Trucks accounted for 127,500 out of the total amount of trucks delivered. [Volvo Group, 2018]

2.2 Production in Tuve factory today

The factory in Tuve produces four models of trucks, namely FH, FH16, FM and FMX. The production is timed so that the truck moves forward in a steady pace through the assembly line and stays the exact same time in each and every part of the assembly. Here the workers are responsible for doing their specific task during their given period of time. These tasks consist of assembling the truck itself alongside the logistics and deliveries of goods and pre-assembled parts to the line. Today all deliveries of parts to the main manufacturing line are carried out manually with the help of different types of forklifts.

2.2.1 Logistics and safety

In ISO-standard SS-EN 1525 [SIS et al., 1997] several hazards are listed which are to be eliminated. These hazards present various risks to operating personnel and should be dealt with in a serious manner. Some of the most relevant hazards for this study that are to be taken into consideration are stated belong:

- Crushing/collisions
- Failure of control systems
- Falling objects
- Movement without an operator
- Insufficient ability to stop
- Unauthorized start up/use
- Lack of stability

The driverless truck must meet the following corresponding requirements, which functions are to decrease or even eliminate the hazards listed previously:

- Breaking system
- Speed control
- Personnel detection means
- Emergency stop device
- Protection against unauthorized use
- Load handling

Areas where the driverless trucks operate are today marked up clearly with colored stripes of paint or plastic. This is done to ensure a safer working environment between trucks and people throughout the factory. In pathways where both trucks and people move there are designated walkways in which people are to walk in, without any deviation.
In this report the AGV will operate in a limited pathway which is a one-way road.

2.2.2 Gearbox beam

The gearbox beam modules are pre-assembled on the side of the main manufacturing line and are shown in figure 2.2. These beams consists of the beam itself with several electronic parts attached. Later on in the production line the gearbox itself will be assembled to this beam. The beams are assembled on top of trolleys that are placed in a certain location when finished. Thereafter they are picked up individually and delivered to the main manufacturing line by a tug-train. Here they are assembled to their right place on the truck. All of this has to be done within the cycle time of 7 minutes and 15 seconds in order to match the cycle time of the main manufacturing line.

Figure 2.2: Gearbox beam placed on a tug-train trolley

2.3 Current workflow

Figure 2.3 shows an illustration of the current workflow. Every cycle at the main manufacturing line is 7 minutes and 15 seconds long and the rout for the tug-trains takes approximately 14 minutes in total. Therefore, two tug-trains, seen in figure 2.4, are needed to supply the manufacturing line with material.
The tug-trains attaches seven loaded trolleys and swaps them with empty ones throughout their rout. When the rout is completed the empty trolleys are left off at their designated stations somewhere in the pre-assembly line.

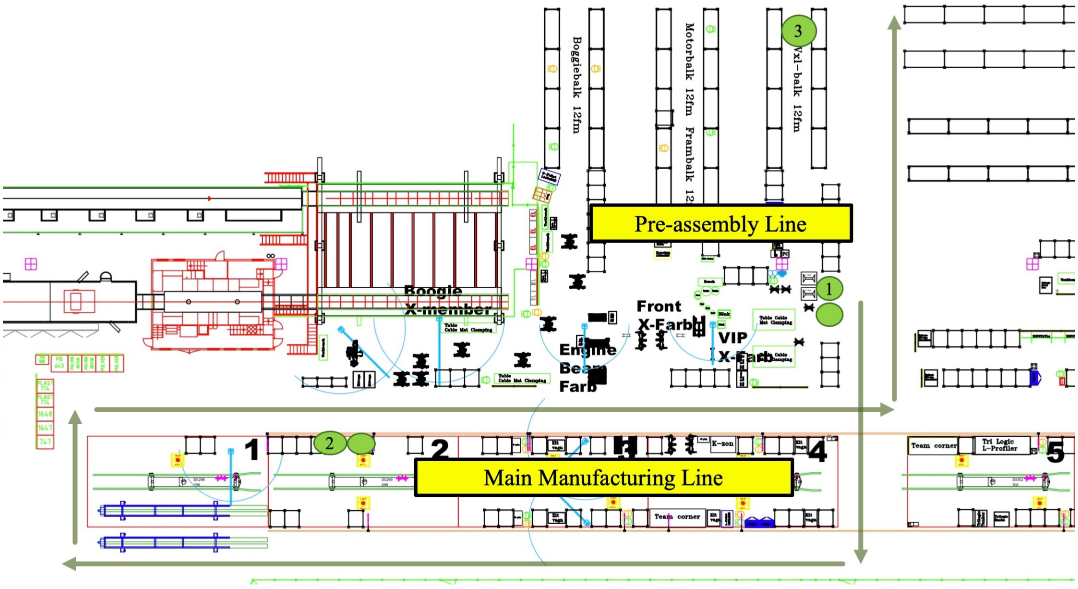

Figure 2.3: Map and illustration of current workflow

The rout for delivering the gearbox beam starts at position "1", shown in figure 2.3. Two trolleys are placed at this position. The design of the current trolleys for the gearbox beam can be seen in figure 2.2. When the operator arrives at position "1", one of the trolleys is attached to the tug-train. The operator then continues the rout and delivers several different trolleys throughout the production line. At position "2" the operator swaps a loaded trolley with an empty one. Finally, the operator stops where the last arrow ends in figure 2.3 and moves the empty trolley back to the beginning of the pre-assembly line. This move is done by crossing a crowded path, which is a sub optimal solution.

Thus, there are three positions where the gearbox beam is handled throughout the rout. The total time for handling these pick-ups and trolley changes is approximately 1 minute and 40 seconds.

Figure 2.4: Tug-train transportation solution
(Source: [Legut, 2018])

2.4 Industry 4.0

It is important to know *why* this kind of case study takes place. This section presents the reader with an understanding for why automated production is a hot topic across virtually all industries. It will include a brief description of the different industrial revolutions and why industry 4.0 is a new revolution.

The concept of Industry 4.0 originally came from Germany and was introduced at the Hannover Fair in 2011 [Kagermann et al., 2011]. Germany is a global leader in manufacturing technology, tooling and equipment. Consequently the German government has a large incentive to keep their manufacturing industries in a leading position and therefore strongly support the development of their industrial sector.

2.4.1 History of the industrial revolutions

Throughout history there has been several industrial revolutions as shown in figure 2.5 which has all led to the one the industry is facing today. The following accounts for a brief overview of the first three industrial revolutions:

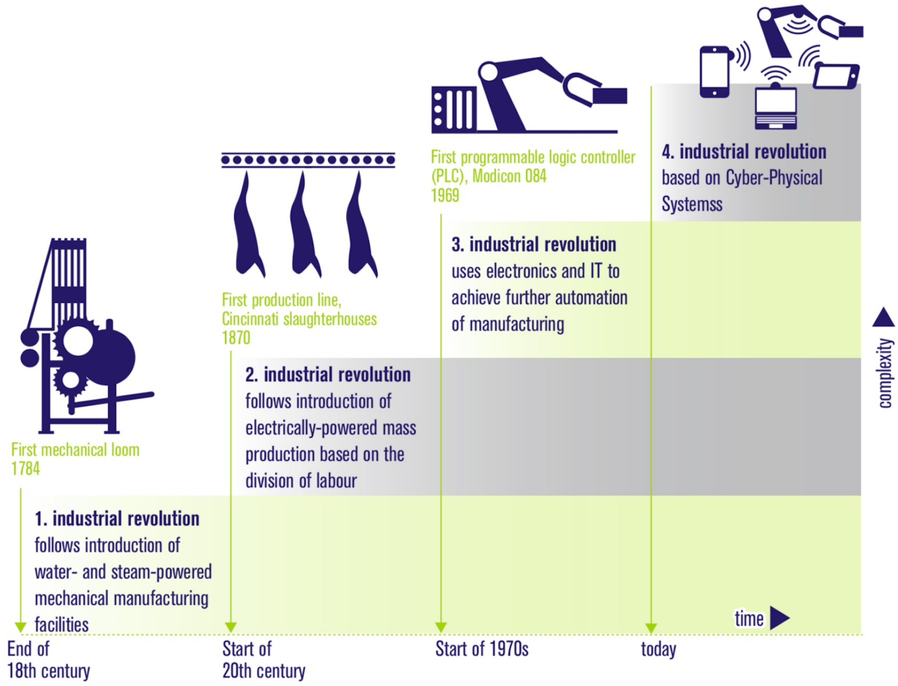

Figure 2.5: The four stages of the industrial revolution
(Source: [H. Kagermann and W. Wahlster., 2013])

1. *The first industrial revolution* took place at the end of the 18th century and was characterized by mechanization [Jean-Paul Rodrigue, 2017] where manual human labor was replaced by mechanical labor. The increased extraction of coal combined with innovations like the steam engine provided the required energy to sustain a large scale of machine manufacturing and introduce mechanization within the agriculture sector.
   Other forms of new manufacturing technologies also emerged in fields such as steel and forging, the textile industry and in the transportation sector.

2. *The second industrial revolution*, also called the technical revolution [Ryan Engelman], took place at the end of the 19th century carrying into the early 20th century. It emerged from the increased use of electricity, combustion engines and the manufacturing and usage of steel. Different chemical synthesis were also developed which led to synthesises fabric, dyes and fertilizers.
   Electrification also provided the means necessary to modernize the telecommunication systems such as radio, telephones and television. These things alongside the expansion of railways and passages opened up and grew the free market between countries and regions. Mass consumption due to the development of the assembly line and large factories where among the more

significant aspects of the second industrial revolution. Often synonymous with Henry Ford and large scale manufacturing.

3. *The third industrial revolution* had its inception in the second half of the 20th century and carries on even until this day. It is also known as the digital revolution [Skilton and Hovsepian, 2018]. Due to an even more sufficient energy supply, for example through nuclear power, several manufacturing technology's could be further developed. This led to even extensive automation processes alongside the development of digital computing. This thanks to breakthrough technology such as the transistor, microprocessor and PLC-programming. Hallmarks of the digital revolution where also the introduction of the information age, driven by the world wide web and disruptive telecommunications technologies. [Skilton and Hovsepian, 2018].

2.4.2 The 4th industrial revolution

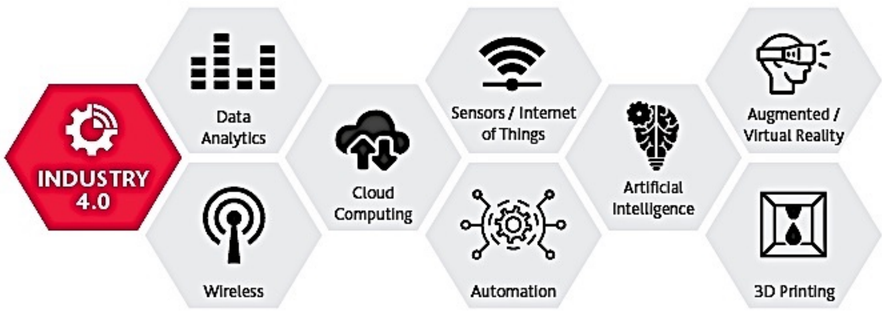

Figure 2.6: Key enabling technologies
(Source: [(BDO) Binder Dijker Otte & Co])

The concept industry 4.0 is a united term for several key technologies. The categorization of these key enabling technologies are divided into eight domains shown in figure 2.6: data analysis, wireless connectivity, cloud computing, sensors/IoT, automation, AI, augmented reality/VR, 3D printing. These domains are established amongst various studies such as [Ustundag and Cevikcan, 2018]. The case study presented in this thesis will not detail these different key enabling technologies other than stating them to give a brief scope of the term industry 4.0. The industrial internet is often refereed to The Internet of Things, IoT, which according to [Skilton and Hovsepian, 2018] can be defined in summary as "Sensors and actuators embedded in physical objects, which are connected to the Internet" (p.11).
According to [Schuh et al., 2017] the development of industry 4.0 can be divided into six stages which are summarized below:

1. *Computerisation*: Even though this stage is well implemented across most industries it is important to note the importance of computerisation.

Generally it enables cheaper manufacturing with higher standards and it provides the link between machines used and business applications.

2. *Connectivity*: This stage builds on the IoT which in short is the connection between physical objects and the internet which in its turn produces massive amounts of data, big data, that are to be analysed and managed. To solve the age gap in technology development in order to enable older objects to stay connected to the cloud new sensors and technology systems can be implemented within old production equipment.
3. *Visibility*: Visibility functions to enable a company for example to track their manufacturing cells and processes in real time by means of a digital model of the factory. The digital shadow can according to [Schuh et al., 2017] "help to show *what* is happening in the company at any given moment so that management decisions can be based on real data." (p.17).
4. *Transparency*: In order for a company to understand and identify *why* something is happening at any given time a root cause analysis must be made. These analysis technologies collect massive amounts of data which is often referred to as Big Data; a modern buzz word. One of the benefits of having transparency in this aspect is the ability for monitoring machinery and equipment and thus enhance maintenance capabilities.
5. *Predictive capacity*: This stage highlights a company's ability to foresee future developments through simulations using the digital shadow, explained in stage three. Thus, answering the question *what* will happen. Being able to plan and simulate various developments is helpful to the company's management team so they can decrease negative impacts and thereby increase productivity.
6. *Adaptability*: Finally stage six answers for *how* an autonomous response can be reached. The aim is for a company to use data from its digital shadow in order to gain an autonomous response based on decisions which are made automatically. An example of this could be to avoid delivery delays by rearranging product orders due to anticipated machine failure.

This case study will only deal with the key enabling technology "automation". No connectivity between the AGV and other order-and productions systems are taken into consideration in this thesis since it only aims to evaluate the initial implementation of the given AGV in production.

2.5 Automated guided vehicle (AGV)

An automated guided vehicle, AGV, is a vehicle without a driver which can navigate itself and perform requested tasks. The idea with having an AGV is to substitute man powered or man controlled trucks or carts with an AGV that can do the same thing automatically. AGVs are typically used for transportation tasks and frequent repetitive tasks where the AGV travels a set rout repeatedly.
The AGV can use different methods for navigating from point A to B. The

methods which are of interest in this report are the following: magnetic strips in the floor and navigation via laser scanners and cameras. In the first case the robot travels over the magnetic strips and follow the magnetic field generated by the strips. The biggest disadvantage with this method is that the AGV can follow the pre-ordered path where the magnetic strips are placed. If the AGV only is desired to perform a new tasks or to take another route new magnetic strips must be mounted on the floor. In other words, each new particular rout requires extra labour in form of placing and removing these stripes. This is a time consuming approach and causes various difficulties.

When navigating with laser scanners and cameras the robot is first manually driven throughout the facility in the areas where it is supposed to operate. While doing so the robot scans the environment and draws a map by itself with the help from its scanners. The map is then used for navigation and route planning when programmed to perform designated tasks. This enables a more flexible way for the AGV to perform different tasks. It can also easily be re-programmed to take different routes and to pick up and deliver goods at new places. [Modern equipment report]

2.5.1 Mobile Industrial Robots (MiR)

Mobile Industrial Robots (MiR) is a company which manufactures collaborative robots, located in Denmark. They offer safe and user friendly robots that to customers to increase their efficiency and automation within their material handling division They offer three different AGVs with different work load capabilities and they also offer different attachments to carry or drag different kinds of goods. [Mobile Industrial Robots ApS]

2.5.2 Competitors

On the AGV market there are a few other companies that manufactures AGVs similar to the MiR presented in this study. Two of the more interesting companies that have been observed mainly during demonstrations at Volvo are Robotize and SEW. Another manufacturer, Kuka, has also briefly been studied in this report.

2.5.2.1 Robotize

Robotize is a company located in Denmark. They are building autonomous vehicles that are made for carrying EU-pallets. [Robotize technology] Their product comes in two models. The first one can carry up to 400 kg with a battery which enables up to 12 hours of operating time. The second one can carry up to 800 kg with an operating working time up to 8 hours. The Robotize's AGV use "light detecting and ranging technology" to draw a map which it navigates through. These sensors also work as safety system by scanning its surroundings to detect various obstacles. When an obstacle is detected the robot will, if there is enough space, automatically maneuver around it. If not, it will plan another rout to reach its goal using its created map.

These products generally have many similarities to the Mir200, which is the AGV used in this project.

2.5.2.2 Kuka AG

Kuka AG is an international company which provides intelligent autonomous solutions to their customers. Kuka are manufacturing all kinds of industrial robots but the ones relevant for this project are their AGVs. Their AGV system is called "Kuka navigation solution" and comes in different variations depending on what task it is supposed to perform. It uses laser scanners and wheel sensors to create a map and to navigate using the SLAM method (Simultaneous Localization and Mapping). According to Kuka there is no chance of collisions due to its laser scanner safety system. These scanners are said to provide the robot with +/- 1mm accuracy. [KUKA AG]

2.5.2.3 SEW

SEW Eurodrive is a global company mostly known for its electric motors and gearmotors [SEW Eurodrive]. In recent years they have been branching out into the AGV market and to other forms of automation. The company aim to sell complete solutions to companies using the standard components from SEW in order to construct complete autonomous systems.
The AGV named MAXO-MS-TV005 is the one that has been studied in this report [SEW Eurodrive, 2018]. This model was demonstrated during a presentation at Volvo Pilot Plane in May 2019.
This particular AGV has a safety system which contains of one "Sick" laser scanner positioned in the front of the AGV and one stop sensor in the back in case the AGV encounters any obstacles while reversing. It uses the same mapping system as mentioned for the Kuka AGV but can also navigate with stripes on the floor if wanted. The TV005 model can carry loads up to 500 kg at a speed of maximum 1,5 m/s with a positioning precision of +/- 10mm according to their catalogue.

2.5.3 MiR200

The MiR200 is manufactured by Mobile Industrial Robots, located in Denmark. This model is the middle model out of the company's three models and it can carry loads of up 200kg. It can also tow trolleys with a maximum weight of 500 kg. The robot is 890 mm long, 580 mm wide and 352mm high without any top modules mounted. The MiR200 weighs 65 kg, has a maximum speed of 1,1 m/s and a ground clearance of 50mm. It is rated for a running time of 10 hours, or 15km of continuous driving. The charging station provides the ability to charge the AGV from 0 to 80 percent in 2 hours. [Mobile Industrial Robots].

For safety and navigation the robot is equipped with two "SICK" S300 laser scanners, one in the front left corner and one in the rear right corner, giving it a 360°viewing angle. The orange circles shown in figure 2.7 represent the safety zones which are dynamic. I.e these zones vary in accordance with the speed of the

MiR. The higher the traveled speed the larger the safety zone in which the MiR stops when objects are detected.
In the front the MiR has two 3D cameras that can detect smaller object close to the floor while driving. As shown in figure 2.8 the camera can detect objects from 50mm to 995mm above the floor level while the laser scanners only detects objects which are located 200mm above the ground.
If the scanners or the cameras detect something while the robot is driving the robot automatically tries to find a way around it. If that is impossible, for example due to restricted zoned in where the robot is not allowed to move, it stops. If it detects something within approximately 50mm around the robot it goes in to emergency mode and stops immediately which is mostly needed when driving in manual mode.

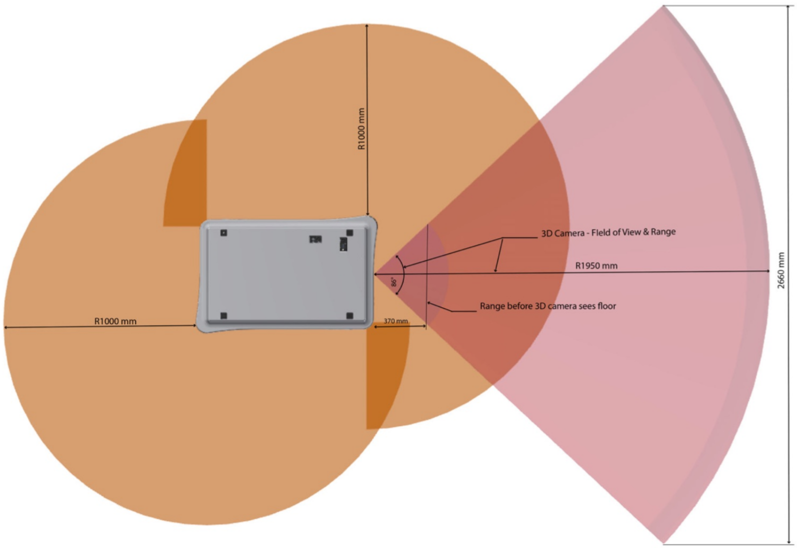

Figure 2.7: Laser scanners and 3D camera top view
(Source: [Mobile Industrial Robots, 2017])

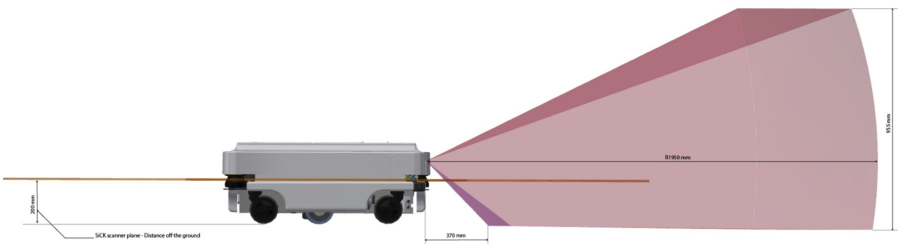

Figure 2.8: Laser scanners and 3D camera side view
(Source: [Mobile Industrial Robots, 2017])

To control the MiR200 or to program different missions, drive it in manual mode and configuring settings etc. the MiR has to be connected to a computer, tablet or phone through Wi-Fi. The software interface is designed to make it possible to

create a dashboard configuration, a sort of home screen in modern terms which is shown in figure 2.9. This to meet the needs and settings which are required for the specific task/tasks that the robot is supposed to complete. In the dashboard one can ad maps, buttons for starting missions, buttons for changing the robots PLC-registers, a joystick for driving the robot manually and different kinds of logs for ongoing missions or errors.
The AGVs from Kuka, SEW and Robotize also use a similar kind of user interface.

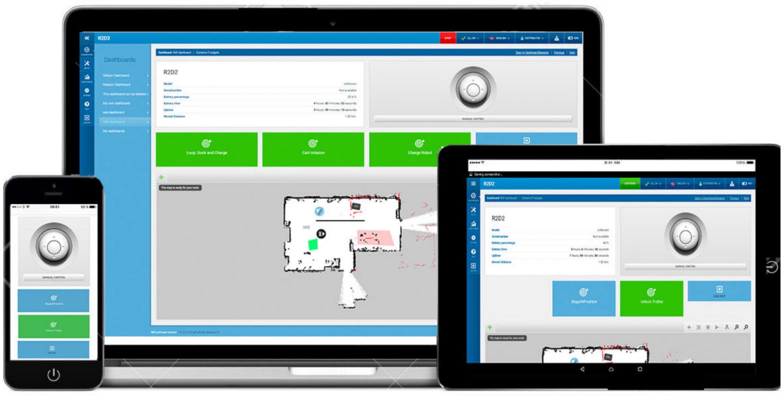

Figure 2.9: MiR200 interface
(Source: [Mobile Industrial Robots])

3
Methodology

The main objection of the following chapter is to account for the methodology used in this study by explaining what has been done and why. It also functions as a tool to conduct a well-planned and thought through study. This chapter will include three main parts: description of methods; analysis, results and conclusion; and finally, implementation of methods. In the end of the chapter the connection between the methods chosen to the research goals will be explained. The beginning includes a brief introduction of the case study and a description of the approaches that have been taken. Throughout the description the reader will gain information regarding how the study has been conducted.
Furthermore, this chapter also aims to provide the study with a solid credibility by outlining the acquisition of data and information and to describe how this data was analyzed, validated and justified.

Validity is often referred to the degree of validity which indicates how well different measurements and observations stack up against the true value. *Reliability*, also called trustworthiness, means to account for the degree of reliability of a particular measurement or method that is used to gain knowledge and results. A high degree of validity most often entail a high level of reliability [Osvalder et al., 2015]. Throughout this chapter methods will be evaluated in terms of their validity and reliability.
The methodology also functions as a guided tour where the reader can follow the study procedure from its inception to its final form.

3.1 Introduction

The task given for this project was to get the given AGV to work in the factory during production. The AGV was used to deliver gearbox beams to the main manufacturing line at the right time in collaboration with its surroundings.
A lot of uncertainties were presented when this task was given. This due to the fact that these types of AGVs never had been used in Volvo's production flow. Therefore, the knowledge and "know how" where limited. No standards or risk analysis had been made for the type of workflow in which the AGV were to be involved. Therefore, the executives at Volvo were keen on having the AGV tested, programmed and validated to equip further decision making with concrete information. This information included surrounding risks and obstacles, various forms of capability, limitations and other findings regarding the performance and potential use cases.

3.2 Methodological approach

The following section will account for the general approach taken while conducting this thesis.

3.2.1 Cross-sectional or case study approach

It is important to evaluate if a cross-sectional or a case study approach is to be taken. In cross sectional studies the emphasis lies on the study of several cases simultaneously with the objective to attain a generalized conclusion [Kate Ann Levin, 2006]. A case study approach narrows its focus on a few selected areas to gain a deeper level of knowledge of a complex problem in a real-life context [Greenwood, 1993].

The goal of this study was to examine the possibility of implementing a new type of AGV in a designated area within the production line. There are no other similar projects or real-life references in use at this time. Therefore, no direct comparisons could be made between different options. This study will consequently fall into the category of a case study approach where a deeper level of investigation in a narrow defined area will be made, within the limits described in chapter 1.3.

3.2.2 Qualitative or quantitative approach

The choice of approach should also be based on whether a qualitative or quantitative research is to be held. According to [Björklund and Paulsson, 2012] the choice of approach should reflect the essence of the report. A quantitative study aims to present measurable data while a qualitative study is made to gain a higher level of understanding of an issue. A study can be both qualitative and quantitative in certain occasions.

The main focus in this case study was to gain information about how a potential workflow with the given AGV could be designed through various testing and research. It was also crucial to present results in a comprehensive form factor that can be used for further development and repetition. Thus, the report is based on a qualitative approach since the aim is to gain deeper understanding of a particular issue.
At the same time the thesis also includes different types of measurements that are made to insure desired performance and validation of thresh holds and capabilities. Implementations of different autonomous solutions are aimed at lowering costs while increasing productivity. Therefore, a quantitative approach is preferred in order to get measurable data to enable comparisons to other types of workflows.

3.3 Description of methods

The following section describes the different sub methods that are used to conduct this case study. The procedure is derived from different sources such as [Björklund

and Paulsson, 2012] and [Osvalder et al., 2015]. Modifications for this particular study have been made.
In figure 3.1 an illustration is shown where the different phases of the project are presented. These phases include sub phases which also are shown in the figure.

The four phases are planning and methodology development, data collection and research, implementation of methods and analysis, result and conclusion. The illustration highlights where the different sub methods occur as a result of the case study planning. Even though the structure is well laid out some of the methods and phases floated back and forth through various iterations and continuous findings and changes.

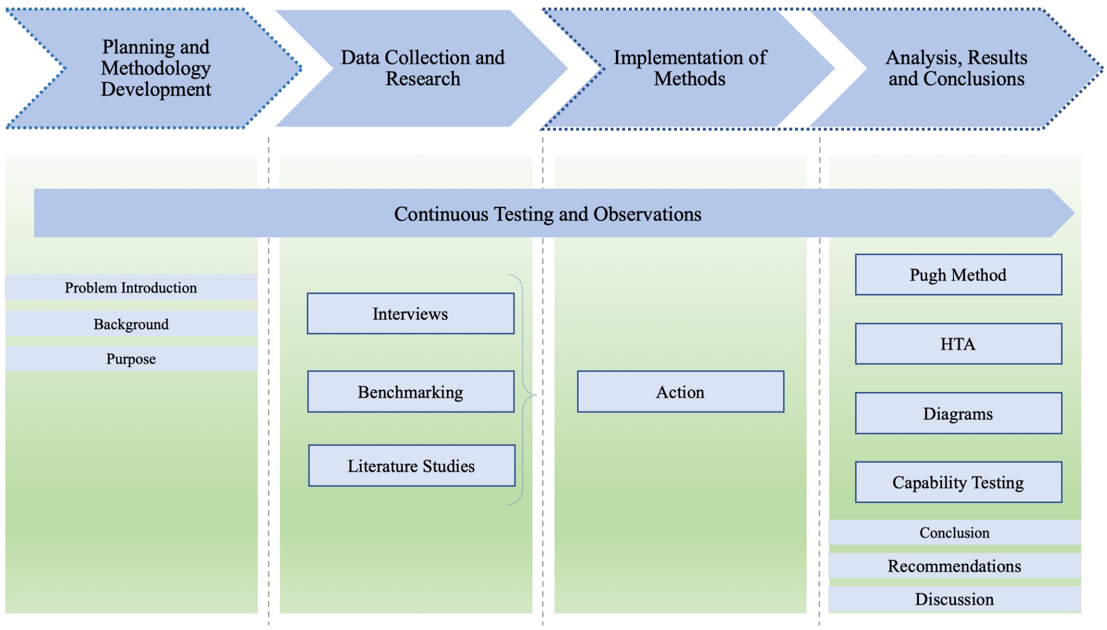

Figure 3.1: Case study phases and methods in planned order
(Source: Own Illustration)

3.3.1 Planning and methodology development

In short this part consisted of the first two chapters. The first one being the introduction where the background, aim and limitations where set. The second one included the theoretical framework where information about the company was collected alongside other ground laying information of about safety, industry history and basic technologies surrounding the study etc.

3.3.2 Data collection and research

This phase included collection of data regarding the actual case study and its practical implementation. Since this thesis has its emphasis on practical parts

some of the data collection were carried out on site. These collection methods were held with executives and workers at Volvo alongside third party participants such as the company who made the given AVG, MiR, and others whom are presented in this study.
Data were collected throughout the study but can be divided into two categories: pre-and during the real implementation of the AGV in live time production. The pre-implementation part aimed at gathering solid information about how the case where to be approached and handled. Interviews, observations and research were made to enable further tasks. Once this was done the data collection during the implementation were made. During the implementation, new data were collected in forms of new findings through observations, interviews and further research. This time the gathering of data were less structured since the results of the implementation were unknown.

3.3.2.1 Literature studies

According to [Osvalder et al., 2015] literature studies contain of theoretical literature, manuals, instruction and technical documentation. Other gathered literature data during this case study came from electronic literature drawn from various sources. Some of these were Google Scholar, company websites and other electronic articles and reports found through broader web searches. These electronic reports were validated through a brief research of the authors and their education level and by examine the sources they used for their work. Some electronic reports were also found though the Chalmers library's database.

Hands on and psychical literature were collected through ownership and loans from the Gothenburg city Library, Chalmers library and through various bought literature that were used for different university courses. By inspecting the references in the used sources additional information were gathered thus, enhancing the studied area.
Additional sources were added above the more traditional literature such as information found on various company websites and internet portals. This data was used to gain information about other manufacturers with the purpose of drawing comparisons to the AGV used in this report.

According to [Osvalder et al., 2015] "a literature study can have the purpose of bringing forth a description of the present knowledge position or to gather knowledge of a particular domain in a certain area" (p.491). These literature studies were necessary for setting the foundation for further implementation and it makes known what already have been done and documented.
In this case study focus was set on articles and reports regarding automated guided vehicles, robot collaboration and safety, risk analysis and to provide a background for the case study. Additional literature was used in order to structure this thesis in a proper way.

Reliability were insured throughout the literature study by comparing different sources to each other i.e. investigating if there were any deviations. The authors were also examined in terms of their education level, a brief overhaul of the sources they had used in their work, if their research were peer-reviewed and sometimes also by judging the credibility of other works they had made.

3.3.2.2 Benchmarking

The concept of benchmarking can be considered as a systematic and civilized form of industrial espionage, as [Osvalder et al., 2015](p. 104) describes it. The core purpose of benchmarking is to improve a company's products and streamline their processes. This is done by comparing them externally with predominant competitors and industry leaders. Comparisons are also made internally with other various operations within the company's own corporations where similar activities are conducted [Bogetoft, 2012]. Benchmarking is civilized in the sense that it is not the copying of others work but merely a way of learning from the best which also enables companies to understand their relative cost position.

[Ovidijus, 2014] argues that there are four main categories for ways of conducting benchmarking:

- *Internal benchmarking*: This type is used to compare processes and functionalities within the very same organisation.
- *External and/or Competitive benchmarking*: The difference between these methods lies in the relative nature of the organisation that is to be compared with. If compared to a company within the same industry, it is call competitive benchmarking whereas external benchmarking looks both in-and outside of the same industry.
- *Functional benchmarking*: This way of comparison is intended to compare results and processes to organizations which are not direct competitors but who perform similar activities.
- *Generic benchmarking*: An example of this is when comparisons are made against the very best, regardless of branch.

To enable a structured way of benchmarking the model in figure 3.2 has been followed, drawn from [Osvalder et al., 2015].

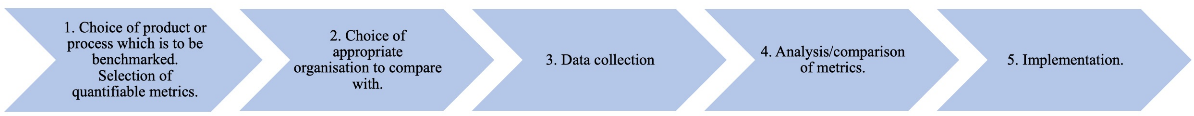

Figure 3.2: 5 steps of benchmarking
(Source: Own Illustration)

This thesis contains benchmarks first and foremost in the form of internal and competitive benchmarking. The internal benchmarking where held at Volvo Trucks, Tuve Gothenburg through observations at site and through video and internal documents. I.e. comparing a potential new workflow with the current workflow. External benchmarks were carried out by researching competitors through online websites. Both on their official pages but also through videos on YouTube and other portals. The research also included interviews and observations during demonstrations by other manufacturers with products in competition with the MiR200.

3.3.2.3 Interviews

Interviews can be defined as a qualitative research technique for gathering information that involves conducting individual interviews to explore their perspectives regarding different topics [Neale and Boyce, 2006]. Through interviews knowledge of people's experiences, values and opinions are obtained and provides an understanding for how people reason. Thus, interviews are subjective to various degrees. Also, interviews allow for interpretation of the body language. [Björklund and Paulsson, 2012] Information regarding emotions, attitudes and requests can be sought out, which is much easier to collect than via observations. There are three main techniques for conducting an interview [Osvalder et al., 2015]:

- *Structured interviews*: Results obtained from structured interviews are quantitative since the interviewee answers questions either freely or with a predetermined gradation. Clear questions are set before the interview and they are asked in a structured order.
- *Unstructured interviews*: These interviews are characterized as a more in depth technique with open questions that allows the interviewees to speak freely and elaborate on their answers. Only a vague idea of topics is prepared for these interviews. Unstructured interviews, often called open interviews, can be seen as a conversation. Here qualitative data are gathered with the possibility of asking follow up questions. A smaller number of people are to be interview in this form compared to structured interviews, which are less extensive.
- *Semi-structured interviews*: This type of interview starts with predetermining what topics are to be treated. There is not any set order in which the questions are to be asked. The questions allow for both open and closed answers and follow up questions can be made.

Mostly semi-structured and unstructured interviews were held throughout this study. Most of them were carried out in person but a few were conducted through email and telephone. In the beginning of the project most interviews were unstructured. They contained a lot of follow up questions and were asked to gain a broad understanding and overview of the problem. Some of them were planned and held in a closed area. Others were held in a more spontaneous manner when opportunities were given. Some questions and topics were predetermined while others were made up as the interview went along. More information about what interviews where made can be found in chapter 3.4.

One challenge while conducting the interviews was to compile and derive data since interviews are exposed to subjectivity. When information was gathered through the interviews a few steps were taken in order to ensure reasonable reliability. One of them was to make sure that the interviewee were well prepared, informed and had extensive experience within the chosen area. Another one was to ask follow up question that allowed the interviewees to elaborate and explain their answers. Thus, lowering the possibility of misinterpretation.

3.3.2.4 Observations and continuous testing

Observations are a method for gathering data about how people, or anything, behave in certain situations. This gives objective information of how products and machines act and are to be interacted with, how tasks are done and what problems may occur. Through observations certain information can be collected without the knowledge of the ones being observed. This helps to pick up information which can be hard to extract during interviews. Observations can be divided into the following categories [Osvalder et al., 2015].

- *Systematic observations*: These types of observations take place when the observer knows what events and what behaviors are to be observe. They are held according to a set schedule.
- *Unsystematic observations*: In this case, no predetermined events are sought to be observed. Instead all happenings are noted.
- *Direct observations*: These take place direct in the present system within the actual workflow.
- *Indirect observations*: During an indirect observation, the observer it not present in the actual environment where the observation is made. These observations are instead carried out through different types of video recordings or simulations.

To conduct this thesis direct observations were mostly made. These took place in real time production alongside observations in a more closed out area, namely Pilot Plant. Unsystematic observations were mostly held initially. This to gain an overall frame of how different workflows functioned and how the MiR needed to be handled. As time went on more systematic observations were held in predetermined areas to gain more precise data. The findings acquired through different observations were recorded by taking notes and through video recording and photography. Continuous observations were held throughout the whole project.
To ensure valid and reliable results the observations were held at several occasions and were also compared with so called sobs (standard operation descriptions) to check if the studied happenings were in line with the designed way of operating.

Continuous tests were made throughout the whole study with the observations taken into consideration. The testing contained of staging various scenarios within the production during days free from production. Some scenarios were also staged in Pilot Plant and others where held in production during lunch breaks. Another form of tests were the ones focused on the MiR itself i.e. testing its capabilities in a variety of ways, which will be reviled in chapter 3.4.

3.3.3 Analysis, results and conclusions

This section describes the different methods of analysis that were used in this project. They were chosen in order to gain relevant results and information. Based on the results several conclusions could be made to provide solid answers to the research questions stated in the beginning of this thesis.

3.3.3.1 Hierarchical task analysis (HTA)

This method is suitable for understanding and structuring the workflow of a certain operation in a figurative way. It is used mainly to detail the steps an object or a person must go through in order to perform a given task to reach a desired result [Osvalder et al., 2015]. The steps of how to conduct a HTA follows like this:

1. Chose a main goal which is to be achieved in a particular task.
2. Divide the main goal into a set of sub goals that must be attained to reach the main goal. There should be around 4-8 sub goals in order to present a foreseeable illustration.
3. These sub goals are once again divided into new sub goals until the analysis has reached a desired degree of detail.

The sub goals at the bottom are called *operations* which contains two types of information: the goal of the operation and the action necessary. A HTA can also be presented in a table.

This study will contain a HTA analysis that where build to describe the overall workflow which were to be implemented within the production through AGV programming.

3.3.3.2 Risk analysis

Risk Analysis is a tool used to detect risks and hazards to avoid incidents and accidents that can lead to personal injuries. [Sveriges expoförbund] The method used when conducting a risk analysis starts with identifying what areas are to be analyzed. That is followed by gathering relevant information to detect risks and hazards. An example could be to gain knowledge regarding the observed workflow and its included operations. The third step is focused on identifying potential risks and to find out how incidents and accidents may emerge. An evaluation of the potential risks then held to predict how often they might appear and what consequences the risks present and how big the need is to do something about it. The last part of the risk analysis is to suggest necessary actions to avoid or eliminate the risks and decide if those actions are adequate [Sveriges expoförbund].

To decide if the AGV was suitable and ready to be used in production a risk analysis was held in the factory with representatives from the safety division, maintenance division, tooling and equipment division, the head of the pre-assembly station and the head of logistics for the studied area.

The risk analysis started with a briefing of the AGV's hardware and its internal systems, mainly its safety systems such as the scanners and cameras. Then the AGV was demonstrated in action carrying trolleys from the pre-assembly station to the main manufacturing line where it picked up an empty trolley and drove back to the starting area.
The demonstration was held during lunch break. Therefore, no other activities were performed in the factory and no other traffic from trucks etc. could interfere with the demonstration. Everyone who participated during the demonstration noted possible risks that later was compiled in a risk analysis document.

3.3.3.3 Pugh's method

A way to compare and rank multiple generated ideas, solutions or concepts is to use a Pugh matrix. The first step is to ensure that all concepts meet the requirements of a set product design specification. This specification is established by the customer or other internal executives who oversee a development project. All these requirements are then listed in the left column of the Pugh matrix. A reference solution is then listed the right of the requirements. This solution is given the score zero on all requirements that are listed in the matrix.
Additional solutions are then inserted in the matrix, on the right side of the reference solution. These solutions are then compared one by one to the reference solution. If a solution is evaluated to fulfill a certain requirement better or worse than the reference it respectively gains a "plus" or a "minus" for each requirement. If a solution meets a requirement in a similar way as the reference, it is given a zero.
Each requirement can also be compared to the others in terms of their utility. Thus, the requirements are weighted with a number accordingly. This weight is then multiplied with the "plus" or "minuses" for all requirements. At the bottom row the sum of the weighted score is stated for all solution. This enables the researcher to compare concepts to one another in a structured way [Johannesson Hans et al., 2013].

This method is used in the report to compare different programming solutions for the AGV. The product design specification where not given in the form of a complete document. It was instead derived from different meetings, interviews and observations throughout the project. The gained requirements were then put together by the research groups for this thesis.

3.3.3.4 Capability testing and inspection at Volvo Trucks

According to a Volvo internal corporate standard [Backman, 2006] a few requirements are presented in regards to the testing and inspection of newly implemented machinery and equipment. Some of these requirements are:

- Function
- Cycle Time
- Reliability performance

- Availability
- Machine capability

These tests are to be carried out under as production-like conditions as possible. Cycle time, reliability performance and availability has to be verified simultaneously. The tests should be held under a number consecutive of days in a row, each one being at least 8-hour long.

The cycle times are to be measured as the mean value of ten consecutive cycles excluding the first and last cycle. These cycle times are to be calculated without interference from other operations. I.e. if an operator who is working on another task than the AGV happens to block the AGV during its operation the time passed should not be included in the cycle time. The average working cycle is to be presented in a distance-time diagram.
This study will focus on cycle time, reliability and availability when performing capability tests.

$$R = \frac{N - N_f}{N} \times 100 \tag{3.1}$$

When the reliability performance is measured equation 3.1 is to be used where N is the number of working cycles and Nf represents the number of faulty working cycles due to the equipment that is being tested.
The standard value of R is required to be above 99%.

$$A = \frac{T - T_d}{T} \times 100 \tag{3.2}$$

The availability test is also to be calculated during an 8-hour period in accordance to equation 3.2. T represents the total operating time and Td represents the total downtime during the time T. The downtime is the time passed due to faults in the equipment which is being tested.
The standard value of A shall be at least 97% which equals a maximum downtime of approximately 15 minutes during an 8-hour period. It is also to be noted that a single stop may only result in a maximum downtime of 5 minutes.

3.4 Implementation of methods and analysis

This section will give an overview of how the different methods were used in this thesis i.e. this section will account for the practical course of action taken for the study. In figure 3.3 the course of action for the case study is illustrated. Each part will be described in a short and consist manner where ties to the method descriptions are made, which are found in chapter 3.3.

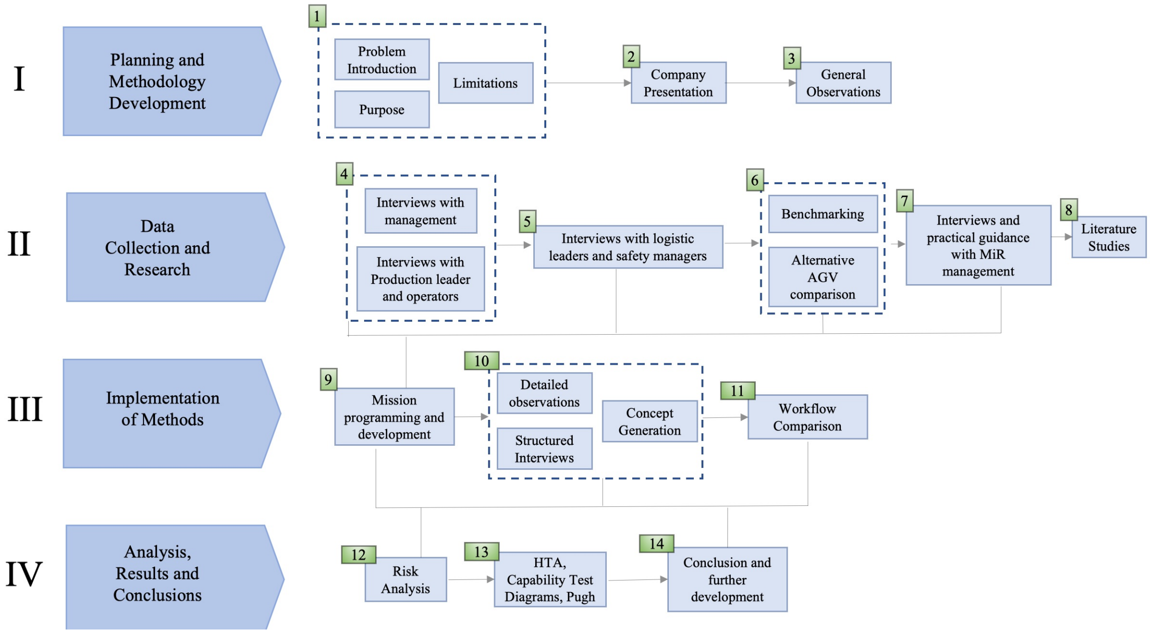

Figure 3.3: Case study course of action Illustration
(Source: Own Illustration)

1. Problem introduction, purpose, limitations:
   The case started by reaching out to Volvo and applying for different bachelor thesis projects. Once assigned with the given case a more thorough description of the problem was presented on cite by Per Anders Alveflo, supervisor for the project. In accordance with this presentation and problem description and a purpose was derived and formed. Research questions were established to match the problem description and to serve the purpose of the project. Limitations were set and the report planning was initiated.
2. Company presentation:
   When given access to the facilities at Volvo a brief company presentation was held by one the production engineering trainees at Volvo, Jonas Fuglås. The same presentation is held for all new employees at Volvo. This presentation mainly concluded of the currents state of Volvo and Volvo's history and vision for the future.
3. General Observation:
   During the first weeks of the case study general observations were made, alongside gathering of data. These observations included an overview of the MiR's interface, hardware and design. General observations in the production itself were also made with the purpose of understanding the current workflow and to get a grip of how the operators worked and to connect the theory of the sought implementation to a practical understanding of the production line as is.
4. Interviews with project management, production leaders and operators:
   These interviews where for the most part held as semi-structured interviews

with open questions, follow up questions and they allowed for open discussions. Some questions where prepared and a certain agenda was set entering the conversation. The target was set on gathering valid data and information regarding how to design an automated solution with the help of the AGV. Throughout the case study similar interviews where held at various points to function as a guideline to the concepts generated in Pilot Plant.

5. Interviews with logistics and safety management:
   To gain a deeper understanding for how the logistics were handled semi-structured interviews were held. The head of logistics at the site where the AGV were to operate, namely Mikael Sällberg, was the key interviewee. He gave different directives that were used in the programming of the AGV. One of them was to program the AGV to only drive on one side of the passage road, regardless direction.
   The safety management team where contacted and interviewed in order to gain information on different safety issues. A couple of concepts were introduced and the safety team had the chance to make comments and assessments. These were all taken into consideration when designing the workflow that was to be tested for implementation.
6. Benchmarking and alternative AGV solutions:
   Studies where made to gather information of what already exists on the marked in terms of AGV technology. Different manufacturers where compared with briefly to understand what other options are available. Since no other AGVs of this type had been used in the factory before the benchmarking had its limitations. Nothing were to be compared with and the comparisons focused on other manufacturers with similar AGV models. Benchmarking against similar workflows in the production at Volvo were highly limited.
7. Interviews and practical guidance with MiR management:
   During the case study help was given from the MiR management team, namely from Peter Ämström, key account manager from Cobot, direct partner with Mobile Industry Robots. He provided new software updates for the AGV and various hardware tools and fixtures. At one point Tobias Borgstrom, support technician at MiR, traveled from Denmark to Volvo Tuve in order to give support to various docking problems. He also held a key lecture in how to program the MiR correctly.
8. Literature studies:
   Data and information were gathered through various literature at libraries, Google scholar and other internet portals. The staff at Volvo also provided the study with internal documents and standards. Other documents given came from MiR themselves in the form of manuals regarding the programming of the AGV and more general guidelines regarding the AGV's hardware.
9. Mission programming and development
   Continuous testing and development of missions for the AGV where

constantly in progress. They were first conducted in a closed area, Pilot Plant, and then tested at the production site during production breaks and days where no production was held. These tests focused mainly on the settings for the AGV. Primitive methods were used including tweaking and trying different parameters and different programming designs. This to examine how to implement the AGV in a sophisticated manner.

10. Observations, interviews and concept generation
    Additional direct observations were held to gain quantitative data regarding the cycle time of the current workflow. Minor details were noted e.g. how different forklift operators worked in the area where the AGV was to operate. More structured interviews were held with working operators in the production in order to verify that the tests were performed in a safe way. This was done in order to avoid disturbing the operators.
    With this information at hand more detailed and mature programming could be carried out.

11. Workflow comparison
    A spaghetti diagram of the current manual workflow was drawn and the same thing was done with the newly designed workflow for the AGV. These two were then compared in order to highlight both potential positives and/or negative impacts of switching workflow.

12. HTA, Diagrams, Pugh and Capability Tests:
    A HTA were designed in order to create an intuitive illustration of the workflow and for the reader to get an overview of the tasks. Diagrams were drawn to show different steps within the workflow and a Pugh matrix where used to compare different programming solutions.
    Capability tests were held to determine if the MiR could meet the requirement standards for new tooling equipment.

13. Conclusion and further development:
    When the final tests of implementation in the production line had been held, a conclusion was drawn and a section focused on further development were presented. These were also based on the findings throughout the whole study to bring answers to the research questions.

3.5 Methods tied to research goals

The following chapter will briefly tie together the research goals with the methodology and the approach that was used in order to answer the research questions.

RQ1: Is i possible to get the given AGV to work in the production at this point?

In order to answer this research question, a key component was to figure out how the AGV functioned and to gather the information needed to program the AGV to

the best of its ability. This was done by researching manuals for the AGV and by rigorous tests in Pilot Plant. Support was also given directly from employees from Mobile Industry Robots and from their affiliated partners.
Observations in the production were made in order to gain knowledge about the risks and challenges and to understand what routes and places the AGV had to travel. Interviews were made with the logistics and production management in order to get directives on what passages were to be used and what hazards to look out for.

RQ2: How can the level of automation within the internal material handling be increased?

The case study was set to explore the possibilities of using the given AGV to perform automated tasks in production. An essential part of increased automation was obviously to decrease the work for the operators. Therefore, different concepts were generated in order to meet the requirements of the production workers and to ensure that their workflow became easier while providing a high level of security and precision.
To answer this question several interviews were held with operators, team leaders and safety managers. The objective was to gather solid information of how the operators wanted to work and how the AGV was to be programmed in order to function with the operators in a fluid way.

RQ3: How is a MiR centered workflow designed in a safe way?

Primarily this question was answered through a risk analysis with several managers at Volvo, including logistic and production leaders as well as the safety team. The aim was to find out and identify the risks of using the AGV and to asses them in the best way possible. Some of the risk could only be handled by consulting the manufacturer of the AGV directly. This by asking them to change the hardware and software for the AGV in order to meet the performance and safety requirements.

RQ4: What are the benefits of AGV automation compared to older and manually operated workflows?

Finally, the current workflow was compared with the old workflow in order to highlight the differences between the workflows and to determine what benefits are gained by implementing the AGV. Formerly interviews with the production leader regarding the current workflow were taken into consideration when this questions was answered. This to gain understanding of how the current workflow were design and what cycle times it had. These interviews also focused on collecting answers regarding what benefits different departments in the production saw in a potential implementation of the given AGV.

4
Empirical findings and analysis

This chapter provides empirical findings and analysis in order to justify the conclusion made for this case study. It is divided into six main categories. The first two are introduced by the development of the design and connection systems between the trolley and the AGV followed by tests and findings made in a closed area, namely Pilot Plant. After Pilot Plant several tests and findings out in the real production environment are presented. The forth category deals with a risk analysis. The fifth category provides the results regarding the programming of the AGV which were set to be implemented. At the end of the chapter comparisons were made between the current workflow and the workflow designed in this case study.

4.1 Design of connection system between trolley and AGV

When designing the connection plates for the trolleys, which can be seen in fig 4.1, an explanation from Per-Anders on how the systems was supposed to work was given. Important measurements and a basic idea for how the design roughly should look like was discussed.

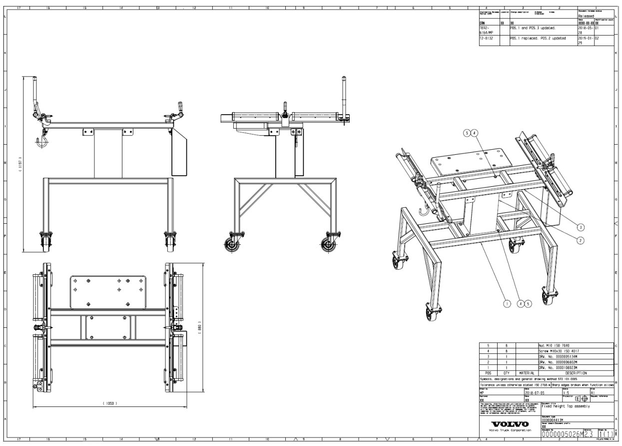

Figure 4.1: The trolley that is being used for transportation of gearbox beams

The idea with the connection system is that the trolley has two pins pointing downwards that fits into a track on the top module mounted on the AGV shown to the left in fig 4.2. This top module has a locking wheel for docking the pins alongside several other electronic components, also shown in the picture. In the right fig 4.2 the top module is shown with its mounted cover plates.

Figure 4.2: MiR200 with top module

To make it easy to both produce the connection plate and to attach it to the trolley it was decided to use the fitting holes and dimensions on the trolley. These are marked by number 4 and 5 in fig 4.1. The dimension on the pins were designed to dock the AGV through the track on the top module on the AGV. This dimension was measured from the difference in height between the top module and the bottom of the lowest horizontal bar on the trolley. This measurement and the design of the pins can be seen in fig 4.3.

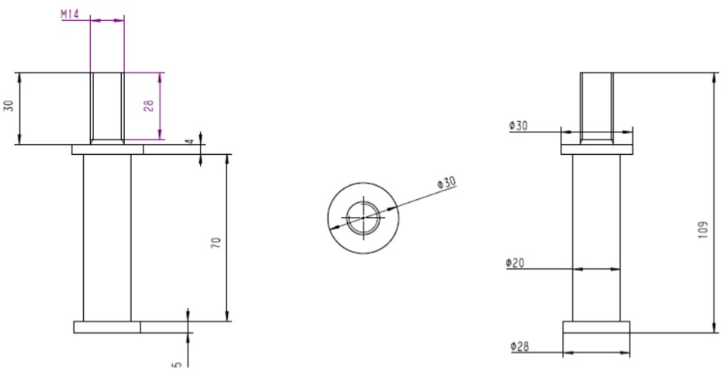

Figure 4.3: The pins that connects the trolley with the AGV

The two different designs for the plate where the pins are mounted are shown in fig 4.4 and fig 4.5. The main idea of the plate was basically to have something to attach the pins to at a position that makes the AGV connect properly to the trolley.

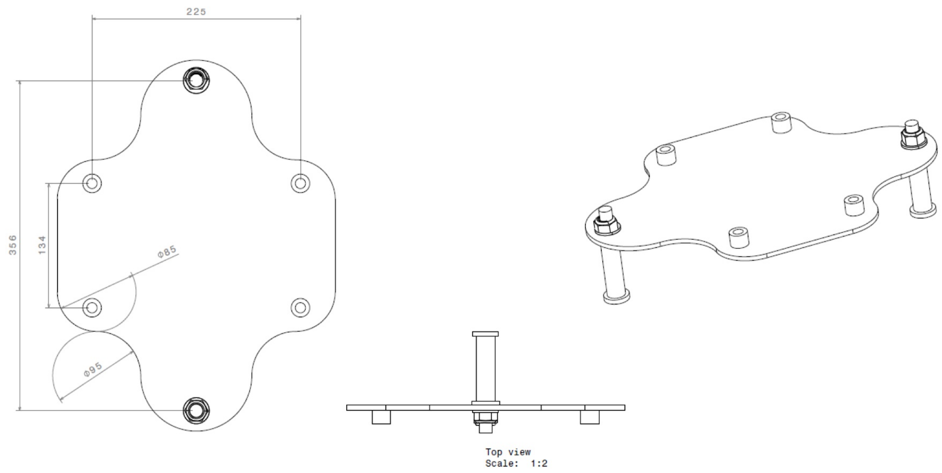

Figure 4.4: The first design for the plates to the trolley

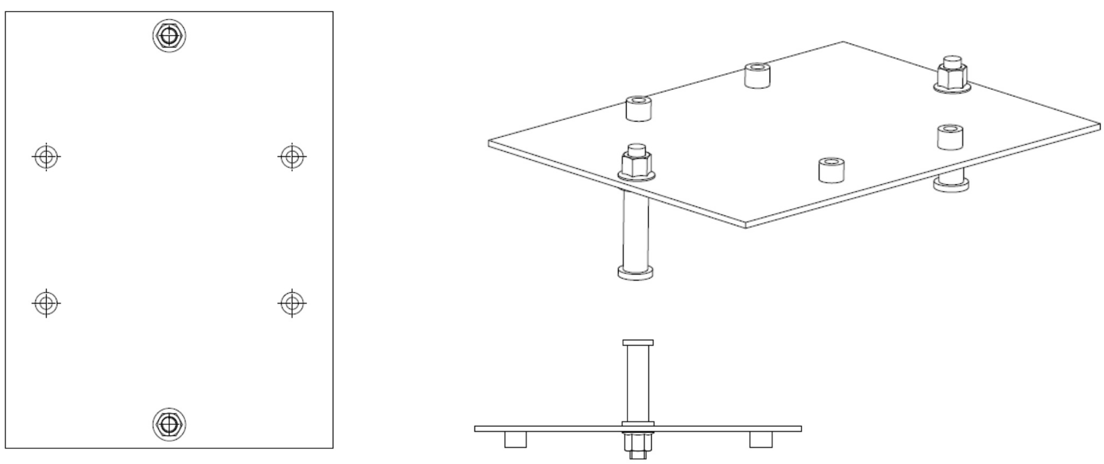

Figure 4.5: The second design for the plates to the trolley

It was clear that the second option was easier to produce due to its more simple geometry. In order to make it easy for the mechanical workshop to produce plates and pins quickly for the 9 trolleys, the second design was decided to be use. The full dimensions and measurements for this plate can be seen in fig 4.5 and an overview of the trolleys with the plate and pins attached in fig 4.6.

Figure 4.6: Trolley with connection system mounted. Side plates used by sensors to navigate during docking

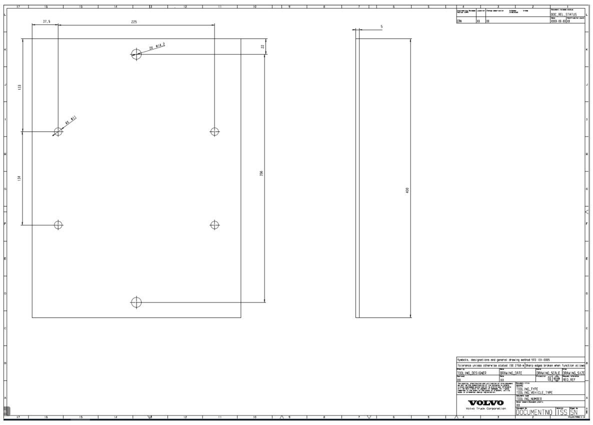

Figure 4.7: The dimensions and geometry fof the side plates

Another important part of the connection system was the thin plates on the sides of the trolleys seen in fig 4.6 and in fig 4.7. The AGV uses these plates to navigate straight when entering underneath the trolley which lets the pins on the trolley to connect to the track on its top module. The AGV's laser scanners are programmed to measure the distance between these plates as well as the distance from the plates to the pins. This enables the AGV to navigate into the correct position properly and thus, ensuring the pins to dock the top module.

4.2 AGV testing in Pilot Plant

In the beginning all tests focused mostly on getting to know the AGV and to program simple mission such as moving from one point to another. These tests

were held in a closed area, namely Pilot plant. New truck models are manufactured and of various tests of equipment and production strategies are held in Pilot Plant. Pretty soon the tests started to get more advanced by adding features to the missions such as different speed zones, sounds, light and letting the AGV do multiple loops and actions.
When the moving missions that were programmed for the AGV were under control the connection system written about in section 4.1 was delivered and mounted to the trolleys. Support was giving from the AGV supplier to get the AGV to function with the connection system. Additional support was also given to program the AGV to pick up the trolleys. Mr. Ämström, key account manager from Cobot, helped with software updates and to set up the PLC registers for the connection system.

4.2.1 Tests with AGV and trolleys

When the tests of the docking and connection process between the trolley and the AGV began, it was noted that the docking was not completely accurate at all times. One problem was that the track in the top module did not dock perfectly to the pin. Therefore, the force of the AGV pushed the trolley forward. Sometimes a lot and other times just by a few centimeters. This caused the AGV to miss the second pin which consequently lead to a failed docking procedure.

To solve this problem the idea was to design a stop mechanism to keep the trolley in the same position even if the AGV happened to push it forward during the docking procedure. Having a stop system to keep the trolley in place would also makes it easier for the operators on the floor to know where to put the trolley. This solution also functioned to decrease the risk of someone accidentally hitting the trolley, putting it out of position. The stops used to keep the trolley in position can be seen in fig 4.8.

Figure 4.8: Stop function due to pushed trolley. Also indicator of proper trolley placement

4.2.2 Results of the docking process

A few weeks into testing, the rate of failure during docking started to increase quite a lot without any change either of area or settings for the AGV. The problem with the docking was that the AGV did not drive straight during the docking process. This resulted in that the AGV either missed the trolley completely or managed to bump the sides of the top module into the first pin.
Another problem was that the AGV started to turn during the docking process when the first pin had entered the track on the top module. Thus, the AGV failed to dock the second pin perfectly. This resulted in that the AGV pushed the trolley away a few centimeters. In some cases this cause the docking process to fail completely.
The first step in trying to get the AGV back on track was to check all the AGV settings and calibrating the scanners. The calibrations did not change anything and changing the relevant parameters in the settings did not at this point do any good either.

Figure 4.9: Docking process

The result was that the AGV was almost completely unsuccessful in consistently carrying out the docking process. After a conversation with Mobile Industry Robots in Denmark they refereed the problem to the side panels on the trolleys, seen in figure 4.6. Their analysis was that the plates did not have an optimal color. They suggested to use a more grey-silver matt paint to help the laser scanners to navigate better. Trying that advice with repainting the side panels resulted in a minor, but notable, improvement for the docking procedure. But it still was not good enough to use in production and clearly a lot worse than it had been in the beginning, even with the black side panels. Getting back to both Cobot and MiR with this feedback made them pay a visit to try and figure out the problem and try the docking with another MiR.

When both Mr. Ämström from Cobot and Mr. Borgstrøm from MiR came to the Tuve factory they tried to reset and re-calibrate the AGV without any success in the docking process. They brought a new MiR200 to the site which docked well, no matter the color of the side panels. When this was shown, they agreed to that something was wrong or had been broken in the MiR which belonged to Volvo. The decision was made to take the faulty AGV back to Denmark for inspection to provide a potential repair or solution. The AGV they brought was left at the factory in Tuve to make this project move on and to enable further tests out in production.

At the end of the case study new findings were made regarding the docking process. Due to the continuous tests throughout the study a particular parameter within the docking settings, namely "parameter for driving more straight during docking", where tweaked and changed into a new value of 0,01. This was a much smaller value than ever used before. The value of this parameter were set to 0,6 by the support team from MiR. This value were tweaked during additional tests from 0,3-0,9 without any major improvements. No one had thought of setting such a low value as 0,01.
Due to this the docking problem that had been a major issue during almost the whole case study was fixed. Unfortunately, all tests in production alongside the risk analysis etc. where conducted before this finding occurred.

4.2.3 VL-markers

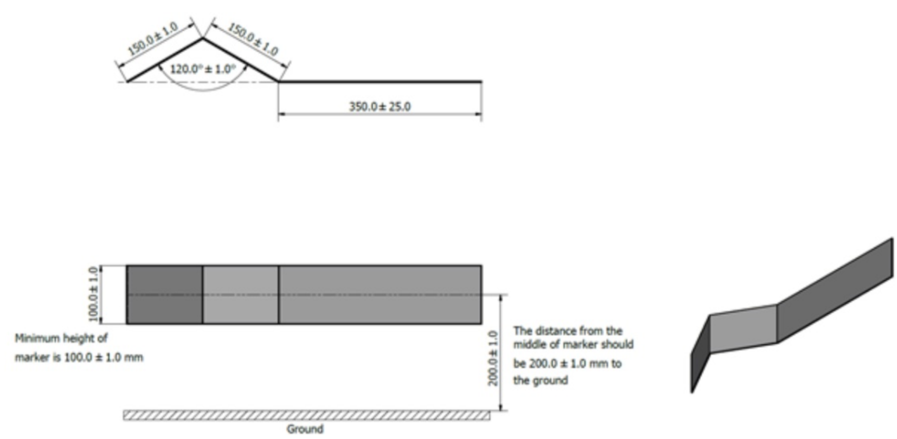

Figure 4.10: VL-marker drawings
(Source: MiR Manual: Use relative markers)

When the AGV is told to move to a set location placed on its map the placing precision is +/- 50mm. This is good enough for most operations but when more precise placements are required relative markers can be used. In this study VL-markers were tested and implemented in some of the missions used in the production. The drawing of the VL-marker and the produced prototype is shown in figure 4.10 and 4.11 respectively. This marker enables the AGV to place itself at a certain location with a precision of +/- 10mm, at most.

When placing the loaded trolley with the help of VL-markers at the main manufacturing line the wheels of the trolley was placed exactly in front of an iron strip, shown in figure 4.11. When the AGV later on was to dock the trolley, the iron strip functioned as stop for the trolley which hindered it from being pushed forward during docking. This decreased the risk of failure while docking.

If the trolley had been placed without the VL-marker the precision would not have been as high. This might have resulted in that the wheels would have been placed a few centimeters in front of the iron strip shown in figure 4.11. When the AGV was docking it sometimes pushed the trolley a bit forward, as described in section 4.2.2. If nothing was directly stopping the trolley from rolling forward the docking was likely to fail. That was why trolleys were placed with the help of VL-markers as an alternative to using the cups shown in figure 4.8.

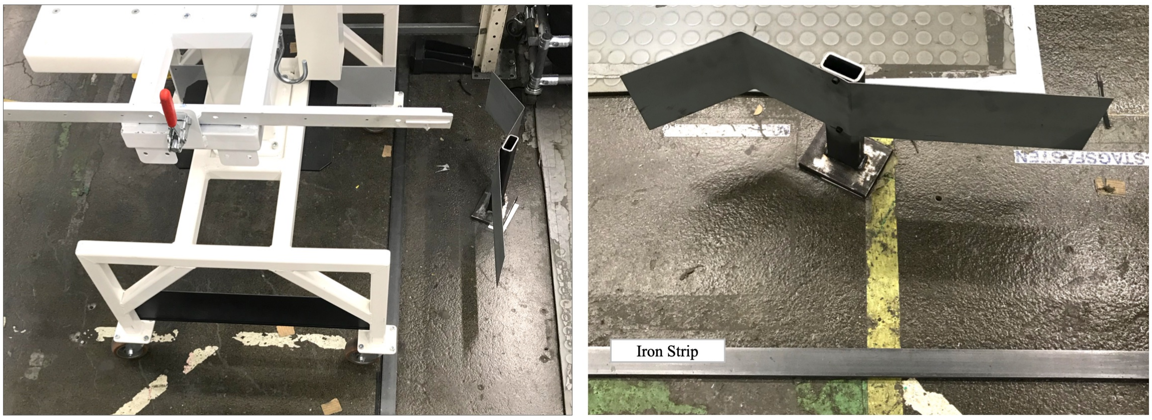

Figure 4.11: VL-Marker prototypes and iron strip

4.2.4 Relative move

A certain type of movement called *relative move* was sometimes useful when programming the AGV to perform different tasks. Relative move is a move relative to the AGV and could be used to make the AGV drive forward och backwards in a straight line. It could also make the AGV rotate on its own axis for a desired number of degrees.

When the AGV performed a relative move and encountered an obstacle it would give the system the message "robot stopped due do collision". If the obstacle was fixed the AGV could not carry on with its mission. When the AGV moved normally from one position to another and encountered an obstacle it would stop for 5 seconds and then retry for a set number of tries. After all tries had been made the AGV threw and error. This error could be dealt with using try/catch-programming, explained in section 4.5.5.2. When a relative move was blocked by an obstacle the AGV did not carry out a set number of retries followed by a thrown error. This disabled the AGV from carrying on with its mission without a manual intervention.

4.3 Testing of AGV in production

After the risk analysis, had been made the head of logistics and the safety division gave clearance to test the AGV in production for half a day. This would show if the AGV could handle the stress and how other operators and truck drivers would interact with the AGV. During the half day test the operators did not have to think about pushing any buttons or controlling the AGV. They only had to put the trolleys in the assigned position to see if the AGV could handle the environment. During this test, all the errors and unexpected situation that occurred were noted. These errors are stated below:

- The trolley did not disconnect from the AGV (the pins where mounted wrong).
- There was only one place to pick up trolleys at pre-assembly
- Beams from other areas where sticking out into the corridor on the way from the pre-assembly line.
- The trolleys were put the wrong way around at the pick up place.
- Tug train blocked the pathway for AGV
- The point where the AGV leaves the empty trolley was blocked.
- The AGV was blocked by a truck and tried to move forward when the truck was working in that area.
- Motor beam in the corridor and the AGV goes around it (make the allowed path for the AGV more narrow)
- Side panel was loose on one trolley.
- AGV failed to dock and pushed the trolley over the stop (check trolley marked with a red dot).
- Error was thrown, telling to "put trolley in right position".

Two additional things regarding the traffic rules were discussed and noted but they did not cause any problems this time. There must be a clearly defined instructions regarding the AGV e.g. who has precedence in the corridor and where should the trucks stop to avoid problems with the AGV. The second thing discussed was that all operators active in the same area as the AGV must get used to having an AGV around and they must understand how it is working.

As the tests went on it became clear that the biggest issue was the collaboration with other traffic. When the AGV detected a working truck in the corridor where the AGV was assigned to travel it sometimes stopped very close to the truck. If the truck proceeded to move just a little bit, the AGV tried to move forward to continue its own mission. This resulted in that the AGV blocked the truck from carrying on with its work.

A solution for this was to program the AGV to move backwards one meter, stop and then wait for 15 seconds before trying to move forward again. If the truck would still be there it would repeat the same procedure again until the truck had moved away. This worked very good until the AGV had an obstacle directly behind it. This could be a wall or a pallet or anyone standing behind it within that one meter distance it was supposed to reverse. When this happened, the AGV stopped and the status shown was "robot stopped due to collision". The AGV could not complete to one meter reverse drive unless the obstacle was cleared which cannot be done for fixed obstacles.

4.3.1 Capability test

The basic theory for conducting an initial capability test of new tooling and machinery at Volvo is described in section 3.3.3.4 where parameters and conditions are defined. These instructions were used to test capability of the AGV in full production using Mission 3 which is described in section 4.5.3. The three test that were conducted were reliability, availability and cycle time.

4.3.1.1 Availability and reliability test

The two remaining tests were held during two half days i.e. 2x4 hours. Due to the scheduling limitations several consecutive 8-hour tests could not be held. Therefore, these tests are not executed according to Volvo's standard criteria, but they gave a predicted result.

N (number of working cycles)	Nf (number of faulty working cycles)
62	11

T (operating time)	Td (downtime)
480 minutes	19 minutes

Reliability
82%

Availability
96%

Figure 4.12: Reliability and Availability measurements

$$R = \frac{N - N_f}{N} \times 100 \qquad (4.1)$$

$$A = \frac{T - T_d}{T} \times 100 \qquad (4.2)$$

The reliability and availability were calculated using equations 4.1 and 4.2. When the results were compared to the standard values of "R" and "A", 99% and 97% respectively, it was made clear that the AGV did not meet the set requirements. 11 out of 62 total working cycles were faulty cycles. The causes for this are stated below:

- *Docking problem*: As discussed in section 4.2.2 the docking process were one of the main issues faced during this case study. These tests were conducted with a non-reliable docking process i.e. before the docking process were solved due to continuous tests, described at the end of section 4.2.2.

Continuous testing was a method used throughout the case study, discussed in section 3.3.2.4.
Four of the faulty working cycles were caused due to a failed docking process. When this happened the AGV and the trolley had to manually be replaced in a new position and sometimes the trolley had to be moved manually.

- *Path way and relative move*: When the AGV drove in the path between the pre-and main manufacturing line it encountered various hinders in form of working operators. They were either crossing by foot, crossing with material, operators on tug trains or operators in forklifts. When the AGV encountered these obstacles, it stopped and after 5 seconds it was programmed to reverse 1-2 meters. But if something was blocking behind the AGV at this stage it stopped, sending the error message "robot stopped due to collision". This error is not like other errors and cannot be taken care of with the help of a try/catch mission, described in section 4.17.
These types of faulty cycles accounted for 5 of the 11 in total.
- *Plastic details on the floor*: The last faulty cycle that was recorded was caused by a plastic detail on the floor which got stuck in the wheel of the trolley.

In order to reach the standard requirements Backman [2006] a few steps need to be taken. These steps are presented in chapter 6, conclusion and recommendations.

4.3.1.2 Cycle time

A cycle time represents the time a certain operation requires. The cycle time for the main manufacturing line was 7 minutes and 15 seconds. This means that each truck reached a new station every 7 minutes and 15 seconds. The cycle time for the AGV is represented in the four stages described in figure 4.14.

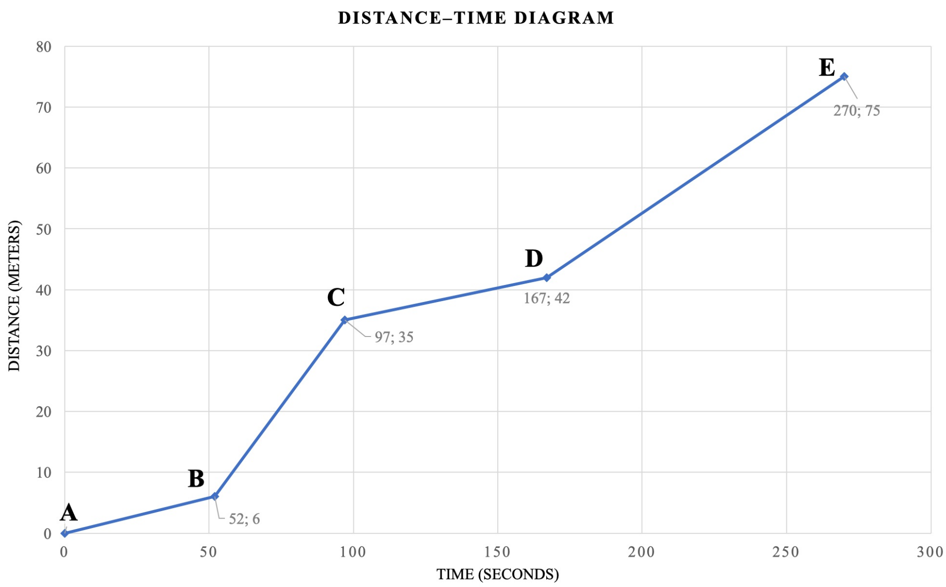

Figure 4.13: Time-Distance diagram

The cycle time test consisted of 10 consecutive mission cycles from "A" to "E", shown in figure 4.14. This led to a mean average cycle time. "A" represents where it starts and "E" where it ends. These positions are located at the same place at the pre-assembly line, approximately at position 3 on the map in figure 4.15. Mission 3 was used for this test which is further described in 4.5.3, which also can be studied through its programming in appendix A.3.

Section	Description	Time (seconds) average*	Distance (meters)
A – B	Pick up loaded trolley at pre manufactory and move to pathway	52	6
B – C	Move to main manufactory line delivery position 1 or 2	46	29
C – D	Place loaded trolley and dock empty trolley	70	7
D – E	Move to pre manufactory and place empty trolley	102	33
		Total Cycle Time average*	**Total distance**
		4 minutes 30 seconds	75 meters

Figure 4.14: Table of total/sectional cycle time and distance

The test was carried out without adding any time to the cycle times due to interference from other operators. Nor were any obstacles in the way of the AGV, as instructed in the capability manual Backman [2006]. The total distance included all minor moves such as docking, un-docking and other minor relative maneuvers. The total rout where divided into four sections to illustrate different phases of the mission. Time and distance data are shown in figure 4.13 and 4.14 above.

The total cycle time of 4 minutes and 30 seconds was 2 minutes and 45 seconds shy of the main manufacturing line's cycle time of 7 minutes and 15 seconds. This gave the AGV a 2 minute and 45 second head room for any unforeseeable hinders during its every cycle.

4.4 Risk analysis

During the risk analysis everybody participating came up with their ideas of safety risks and risks that could mean interruptions in the production. The following risks was identified and noted:

- The AGV runs out of battery and can not be used.
- The AGV breaks and can not be used.
- The AGV runs into a person.
- The AGV runs into a truck.
- A truck runs into the AGV.
- The AGV runs into a pallet lifted by a truck (meaning it is in the air and can not be seen by the AGV).
- The AGV runs in to a fixture that is sticking out in the air from the pre-assembly area.

- There is no "traffic rules" regarding the AGV yet.
- The route of the AGV is travelling against a one way corridor.
- There is not a full set of spare parts to AGV in case it breaks down.
- The maintenance division does not have competence and instructions on how to repair the AGV in case of break down.
- The AGV is difficult to see when it drives out from covered spots.
- The AGV gets stuck on cable ties and other garbage on the floor.
- It is difficult for the tug-train to drive past the AGV.
- The truck drivers might experience a higher level of stress if they must wait for the AGV.
- The team leaders lack competence on how to manually handle and control the AGV.

4.5 Mission programming evaluation for the AGV

All evaluated missions that were programmed for the AGV can be found in the appendix. The evaluation of the missions is shown in the Pugh matrix in figure 4.19. All missions started with the operators placing a loaded trolley at position 1, shown in figure 4.15.
The programmed code for all missions can be seen in appendix A. An overview of the function for each mission is presented in the list below the following figure:

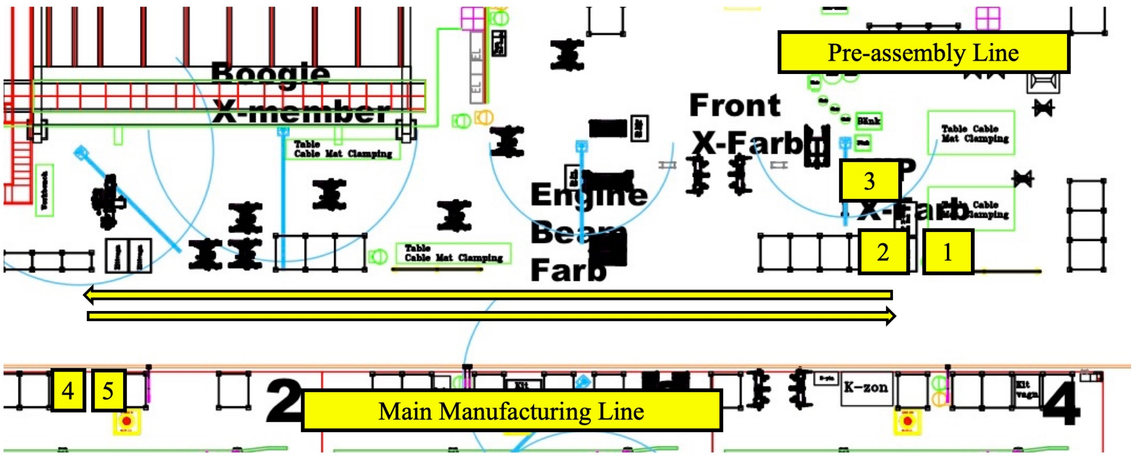

Figure 4.15: Check point positions for the AGV in the workflow

4.5.1 Mission 1

This mission was the first basic mission that would solve the case at the lowest level of automation. Mission 1 is not a loop, as seen in Appendix figure A.1. This means that it had to be restarted once its full cycle had been completed. When the pre-assembly line placed a new loaded trolley ready for pick up they pressed a mission button on the iPad which queued mission 1. When a mission is queued it is placed behind the ongoing mission and waits for it to end. If the queue is empty the mission starts immediately. The following function was programmed:

1. The mission started checking if the AGV was charging with or without a trolley attached. If no trolley was attached the AGV would quit charging, place itself at position "2" and then quit the mission. After this the AGV was ready for a new mission. If a trolley was attached the AGV would find its way to the place where it was before it was called to charge.
2. At the ready state the AGV picked up the loaded trolley and placed itself in position "2" shown in figure 4.15. Here it would wait for the main manufacturing line to off-load the beam from the trolley already delivered. It also payed attention to if there was a halt in the production which meant that it needed to charge.
3. Once the main line had off-loaded the beam they pressed a button on the iPad and the AGV then moved to position "5" and placed the loaded trolley. After that it picked up the empty trolley and drove it back the pre-assembly line and leaved the empty trolley there. To finish the mission, it placed itself ready for a new cycle right next to the delivery place at position "3".

This mission required the operators at the main line to manually move the empty trolley from position "5" to position "4" during every cycle. At position "4" it was to be placed in the cups shown in figure 4.8.
Mission 1 was chosen as the reference for the Pugh matrix.

4.5.2 Mission 2

Mission 2 reached a slightly higher level of autonomy. The operators at the main line did not have to move the trolley once it has been off-loaded. They would have two buttons on the iPad on which they pressed one or the other to tell the AGV where there was an empty slot for placement. The mission was divided into the following steps:

1. The mission started with the AGV picking up the loaded trolley. It then placed itself on position "2".
2. Here it waited for a command from the main line. Either the line presses button "1" or "2" on their iPad screen. Button "1" if they off-loaded the trolley at position "4" and button "2" if they off-loaded the trolley at position "5". In addition to this the AGV also regularly checked if it needed to charge due to any halt in the production.
3. From here the AGV then drove to the empty slot where it placed the loaded trolley. The AGV then picked up the empty trolley and placed it at the pre-assembly line once again.
4. Before ending the mission the AGV checked if the production had taken a break. If so, it would go to charge at position 3. If not, it would end its mission and start waiting for a new one.

4.5.3 Mission 3

This mission had the highest level of automation aside those who included I/O modules in the form of a sensor or physical buttons. For example, a laser-or an inductive sensor.

The mission contained an endless loop that could only be ended when the production takes a break or ends for the day. It required minimal effort from the operators. In contrast to mission 1 this mission was intended not to use the cups shown in figure 4.8 at the main manufacturing line. Instead it used VL-markers, shown in figure 4.10, to enable a more precise placement of the trolley. It would place the trolley just in front of the iron strip shown in figure 4.11. Why this method was used is described in chapter 4.2.3.

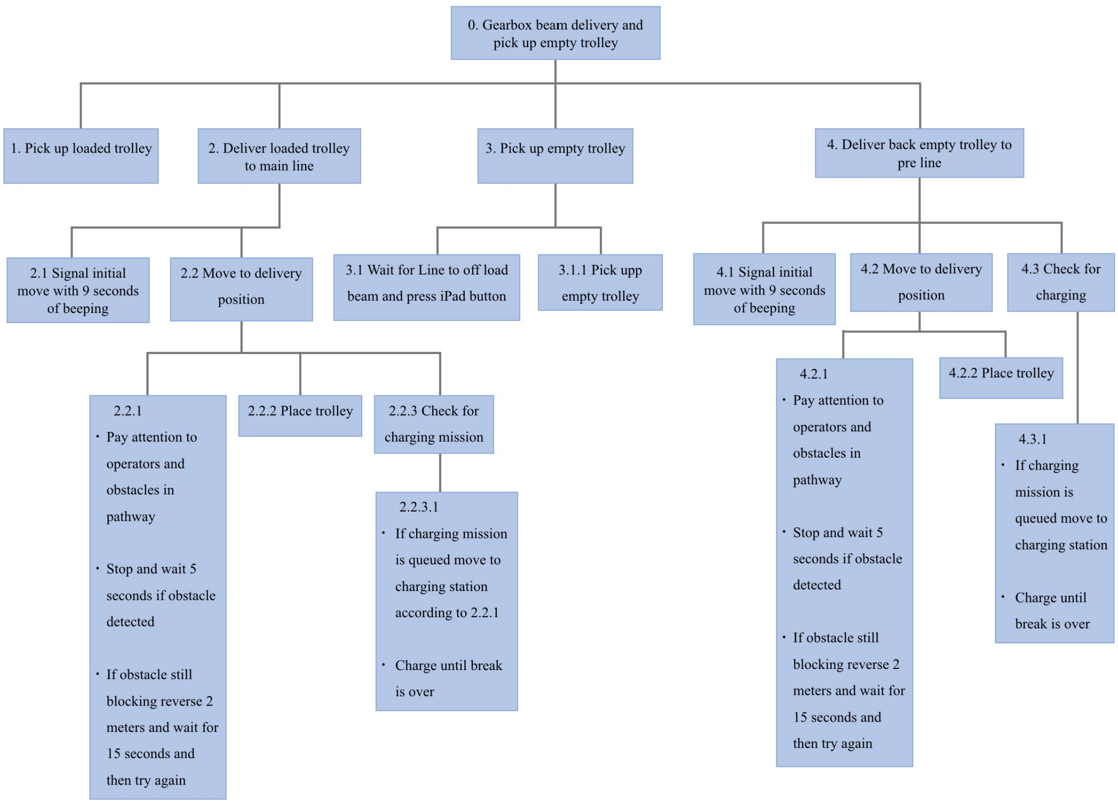

Figure 4.16: HTA for mission 3

Mission 3 is figuratively demonstrated in a HTA showed in figure 4.16. A simplified description of the mission is broken down in a few steps:

1. In the beginning of the mission the AGV picked up the loaded trolley at the pre-assembly line and then checked which slot on the main line that was empty. Every time the AGV delivered a loaded trolley it registered the placement position. This information was then used every time the AGV picked up a new loaded trolley at the pre-assembly line.
2. Once the AGV decided what position to place the loaded trolley it moved to

the given position and placed the trolley there. Here it stopped under the trolley and waited for two things simultaneously:

- The first one was to check if the production had taken a break. If that was the case, the AGV would drive back to the pre-assembly line and charge itself until the production started up again. Then it would place itself at position "2" shown in figure 4.15. At that position, it would wait for the main line to off-load the trolley placed during the previous cycle. This would be indicated with an iPad click.
- The second thing it waited for was for the operators to off-load the previously placed and loaded trolley. After the operators had off-loaded the trolley they pressed a button on the iPad. The AGV waited under the trolley it just delivered until this point.

3. When the operators had off-loaded the previously placed trolley and pressed the button on the iPad the AGV then picked up that empty trolley and placed it at the pre-assembly line. Once again it checked if it needed to charge due to a halt in production. Then it would automatically restarts the mission.

4.5.4 Mission 4

This mission was similar to mission 3 both in terms of level of automation and in terms of how the mission was built up. It consisted of an endless loop that kept going until someone or something manually told it to break. This gave it a lower level of automation since someone needed to specifically go and tell the AGV when there was break.

It used the same kind of VL-markers as in mission 3 but there would be an I/O module placed on the production line. This module gave an input to the AGV when it was time to pick up the empty trolley. This I/O module consisted of either a button or sensor. The sensor obviously would give a higher level of automation. The button would have the same function as the iPad button. The benefit of using and I/O module was that a physical button was easier to operate than an iPad button. Below the steps of this mission are listed:

1. The mission started and the AGV went to the pick-up position to pick a loaded trolley at the pre-assembly station.
2. The first time the mission ran PLC registers 40 and 41 had to be set. This told the AGV which delivery position at the main line that should be used first. Using PLC 40=1 while PLC 41=0 meant delivery to position "4" and PLC 40=0 while PLC 41=1 meant delivery to position "5". The AGV then read these PLC registers for each cycle and delivered the trolley to the correct position.
3. When the AGV arrived and docked at the position it also disconnected from the trolley but stayed under it. It then waited for the operators on the main

manufacturing line to push the button on the I/O module that would send a signal to the AGV which told it to pick up the empty trolley.

4. The AGV then docked to the empty trolley on the position next to the delivery position. Then it drove the empty trolley back to the pre-assembly station. After this the AGV started the loop from the beginning again.

4.5.5 Sub missions, try/catch and charging mission

When the missions were designed a few other programming methods were used to make them more manageable. Some of these methods are described below.

4.5.5.1 Sub missions

Every mission presented involved *sub missions*. These were called upon at certain points throughout the main mission. While checking the code in Appendix one can note the term "run" is followed by a task. This task is a sub mission that has been pre-programmed, often with variables. For example, the sub mission "Place variable line" included several types of try/catch programmings. It also included a variable which were to indicate where the trolley should be placed. This variable was set to a desired location in the main program where the sub mission was contained.

4.5.5.2 Try/catch-programming

Try/catch-programming is an error handling programming method for dealing with various unpredicted events throughout a mission.

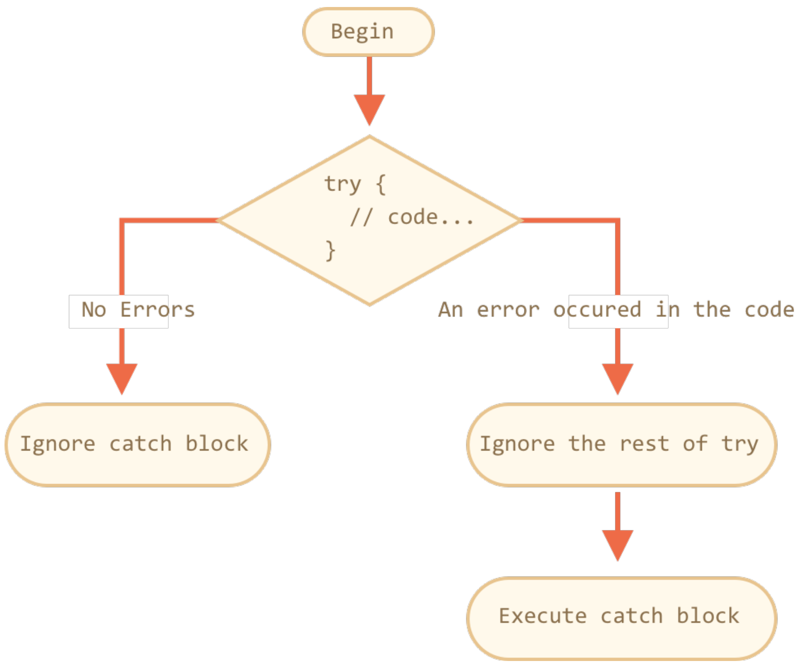

Figure 4.17: Illustration of Try/Catch-programming
(Source: Kantor [2019])

The basic function of a try/catch-script is illustrated in figure 4.17. A try/catch-script begins with trying an operation. If no errors occur the code will continue. But if an error occurs the try-part will be ignored and the operations in the catch-part will be executed.

One important question asked during the risk analysis was how the AGV should deal with ongoing traffic in the passage between position "2" and "4"/"5" shown in fig 4.15. This passage is heavily trafficked and forklift operators loads and unloads material in form of trolleys and pallets at different points in the passage. When the AGV encounters these operators, it stopped and then re-tried to get pass. This was a problem because the operators needed some space to perform their tasks.

"Place variable line" is a sub mission presented in Appendix figure A.6 which included a few try/catch operations. One of them was when the AGV *tried* to move from position "2" to either position "4" or "5". When it encountered some sort of obstacle it stopped for 5 seconds, then it tried to move again and if the obstacle was still there the program threw an error. This error is handled in the *catch* part. The catch part in this situation told the AGV to reverse 1-2 meters and then wait for 15 seconds before trying to move to position "4" or "5" again. This loop goes on until the AGV reached its set destination. All sub missions that included moving between positions like this included variants of this try/catch operation.

Another try/catch programming was included the sub mission "pick up variable line" and it went into effect when the AGV picked up a trolley. If the AGV was not able to dock the trolley, for a variety of reasons, it would reverse 1 meter and place itself in the entry position for the trolley and then try again. The program gave this procedure three tries and at each error it sends a sound message to indicate that there was a problem. If a third straight error was reached the program showed a message on the iPad where the operator was told to place the trolley at the correct position.

4.5.5.3 Charging mission

This mission was the most simple one and it told the AGV to move to the charging station where it begun to charge. The AGV charged until the halt in production was over. The difficulty with this mission lied in the way the mission was called upon and what happened after the charging.
When the operators took a break they pressed the charging button on the iPad. This button placed a new mission in the mission queue, right after the ongoing mission. At certain points throughout the main mission loop the code checked if there was a pending mission placed in the queue. If the charging mission was placed in the queue the AGV would move to the charging station at position "3" shown in figure 4.15. The AGV would then charge until the main mission was put in queue. This would happen when the operators came back from their break and pressed the main mission button. The charging mission was programmed to end whenever a new mission was queued.

One additional challenge with the charging mission was to program the AGV to find its way back to where it was before it went to the charging station. This was solved with setting different PLC-register values throughout the main mission at the end of key operations within the program. PLC-register 25 was mainly used which can be seen throughout the code of all missions presented in the Appendix. When the main mission started over again the AGV would run through the code until it found out were in the program the AGV was before the charging had begun.

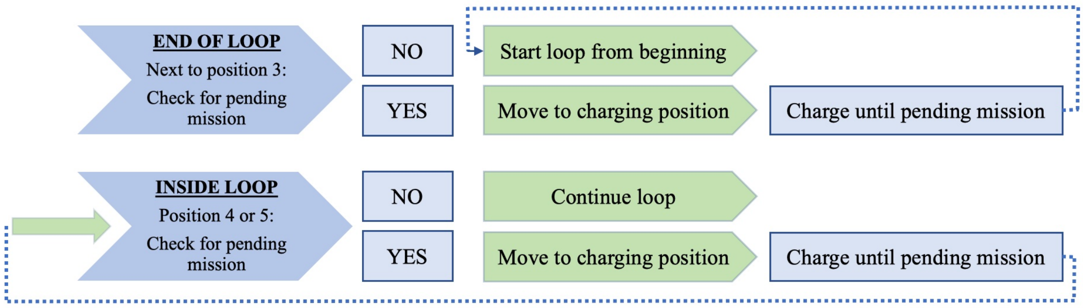

Figure 4.18: Illustration of charging procedure

An illustration of the charging procedure can be seen in figure 4.18. A pending mission during production is equivalent to the charging mission. This mission was called upon when there was a break in the production. A pending mission during the break was equivalent to the main mission loop, which were initiated when the break was over.
At that point the AGV did one of two things depending on where it was located before the break. The first possibility was to move back inside the loop and get ready to pick up an empty trolley at position "4" or "5". The second possibility was to start the loop from scratch since it just had finished a cycle before the break.

This form of programming with PLC-registers was very useful in various aspects e.g. when the AGV had to be shut down manually due to an unexpected event. When the problem had been handled, the mission could start over again and the AGV would proceed from where it was before the shutdown. If this method had not been used the operators would have to move the trolley manually to complete the cycle.

4.5.6 Mission comparison and evaluation

To help understanding and deciding which of the missions that would be most suitable for usage, the Pugh-method was applied.

The missions were first named from 1-4, one number for each mission. The Pugh method was chosen because it was a convenient and practical way of illustrating the best possible solution for the implementation of the AGV. Mission 1 was used as reference.

However, the capability of the programming software was limited which meant that the best desired solution was not possible to execute.

Requirements	Weight	Mission 1	Mission 2	Mission 3	Mission 4
Less job for operators at the main line	1	REFERENCE	+	+	+
Less job for operators at the pre-assembly line	1		0	+	+
Charging mission pending	1		0	+	+
Automatic start after break	2		0	0	0
The AGV finds its way back into the loop	2		+	+	+
Amount of buttons to press	2		-	+	+
Physical button	2		0	0	+
Placing trolley in alternating slots at main line	2		+	+	+
Programmed with Try/Catch-movement	3		0	+	+
Precise placement +/- 10mm at main line	2		0	+	+
Signaling when entering passage corridor	1		0	+	+
Wait for off-load command at main line	1		0	+	+
Loop function	2		0	+	+
∑+			3	11	12
∑-			1	0	0
Sum			2	11	12
Weighted Sum			3	18	20
Rank			3	2	1

Figure 4.19: Pugh matrix for ranking solutions

As seen in fig 4.19 mission 3 and mission 4 got a very similar score and had the same advantages on practically all the same points. Mission 4 had the advantage of a physical button instead of an iPad button. However, in order to get the AGV to be as resistant as possible to failure it was decided that mission 3 was the best to use. Mission 3 used a PLC-register instead of an I/O module to indicate when the operators had off-loaded the trolley. The problem with the I/O module was that the AGV could only read the input when the AGV was actively waiting for an input from the I/O module. This was a problem that was judged to only being possible to solve by adjusting the internal software.

The PLC however could be set to a value and stay that way until changed. This allowed the operator at the main manufacturing line to give the command indicating that the beam had been lifted off at any point. Where the AGV was located in its cycle at this point would not matter. Once the AGV had delivered a new loaded trolley, it would check for the PLC-register for the lift off action. If the PLC-register had been switched to "1" it would pick up the empty trolley. If not, it would wait for the operators to click the PLC button, which would set the PLC-register to "1". Thus, telling the AGV to pick up the empty trolley. When the trolley had been picked up the code would re-set this specific PLC-register to "0".

4.6 Workflow comparison

The designed workflow centered around the AGV is figuratively shown in figure 4.20. The passage in which the AGV drove is a one-way passage. Mr. Sällberg, head of logistics at the given area, had given the AGV permission to drive both ways. Since the tug-trains drive on both sides of the road it was decided through the risk analysis that the AGV should only drive on the left side of the pathway.

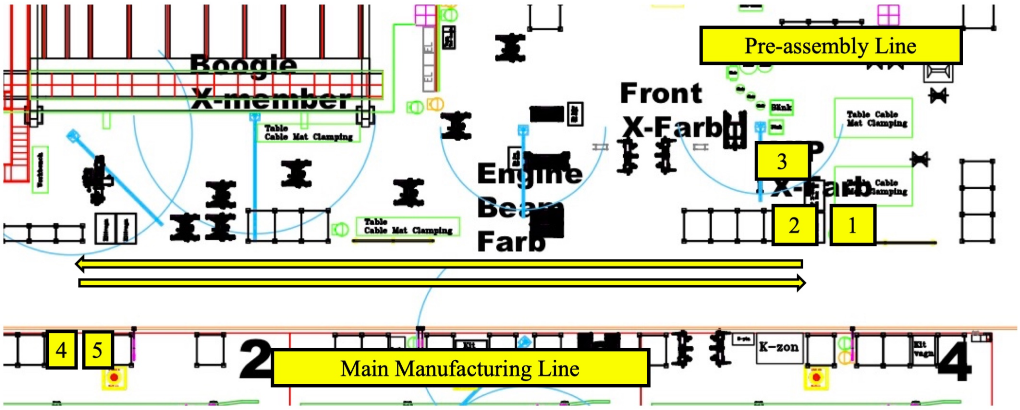

Figure 4.20: Map and illustration of designed workflow

The spaghetti diagram in figure 4.21 shown an illustration of what moved the AGV was designed to take. Letters A-E represents key operations throughout its mission. The cycle time for the whole work cycle is approximately 4 minutes and 30 seconds which is presented in greater detail in section 4.3.1.2. Figure 4.14 shows additional information to the cycle time by dividing the work cycle in to sub parts from A-E.

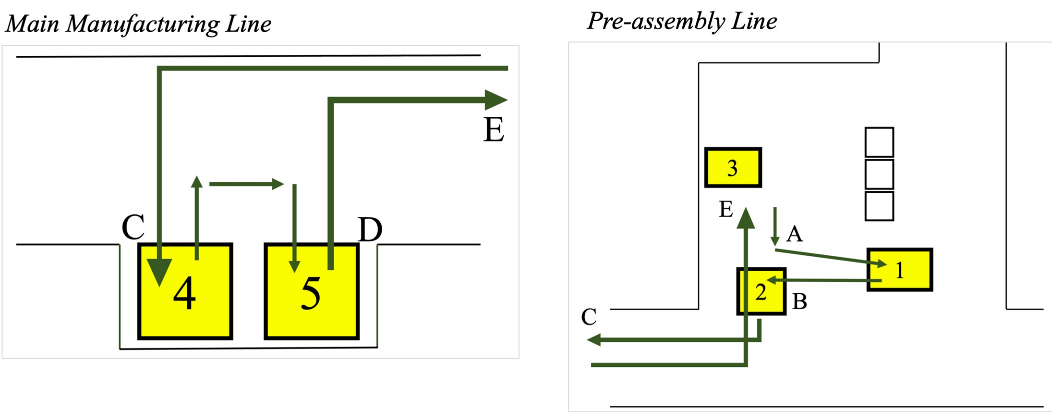

Figure 4.21: Spaghetti diagram of designed workflow

The current workflow with manual operators uses approximately 1 minute and 40 seconds in order to pick up the loaded trolley from the pre-assembly line, to change it with the empty one and finally to leave the empty one at the pre-assembly line.

This is done at position "1", "2" and "3" shown in figure 2.3. This time is spent with the tug-train standing still in different areas in the pathway.

The cycle time capability test showed that the time spent between C-D took 70 seconds, if there was no interference. These 70 seconds represented the part of the cycle time where the AGV was changing trolleys within the pathway. Thus, being a hinder to other operators which also were working in the pathway. This operation was carried out in an area of approximately 4 square meters. The operation time was compared to the time passed when the operator stopped the tug-train at its three positions shown in figure 2.3 and manually moved the trolley. The AGV was on the move in sections A-B, B-C and D-E i.e. it was not operating standing still in a small area as in C-D.

This resulted in a 30 seconds' difference between the workflows. The AGV took additional time to pick up the loaded trolleys at the pre-assembly line and to leave the empty trolleys at the pre-assembly line. However, this operating time was spent within the pre-assembly area where the AGV was no hinder to other truck traffic.

5

Discussion

This chapter will start with a general discussion followed by criticism of the methods used.

5.1 General discussion

During the whole project one of the biggest problems have been the part where the AGV dock to the trolley. To fully fix this problem something needs to be done with the software for the docking process to make it more accurate and stable.
At the same time as this project took place, Volvo was also testing another AGV, MiR500, in Pilot Plant. This one differs a bit from the MiR200 and is designed to carry pallets. However, the interesting thing was that when the MiR500 was docking to the pallet station it drove straight and docked perfectly every time. When discussing this with Mr. Ämström from Cobot he explained that there is a software difference between the two models regarding the docking procedure. Apparently the MiR500 is better at navigating to its entry position and to put itself in the right direction to enable a straight drive into the pallet.
What probably should be tested in a future step is to incorporate the same software system for the docking procedure in the MiR500 as the one in MiR500.

At a late stage in the case study an new finding was made within the settings of the AGV that solved the issue of failure during docking. A certain setting named "parameter for driving more straight during docking" were changed to a much lower value than before which resulted in a perfect docking sequence.
This should on the other hand not exclude a test of another software system for the MiR200.

The aim of this project was to evaluate if the MiR200 could perform the task of delivering gearbox beams to the main manufacturing line. The goal was to make it work in production before the summer. It is now clear that this goal was to great and could not be achieved to to several factors, presented in chapter 6. A better idea could have been to break up the goal in smaller steps, which probably will be done in the future. For example, a follow up project to this one should be launched with the goal of perfecting the docking procedure. Another project could then be launched which focused on creating new traffic rules and manuals for how the AGV needed to be handles.

One of the challenges with this project was to get the AGV to work in collaboration with the truck drivers and other logistic processes in the factory. The

problem with this was that there was not enough time that could be spent out in the factory due to the lack of days free from production. This meant that all the possible scenarios that could occur had to be anticipated and recreated as good as possible in Pilot Plant.
When the tests in Pilot Plant had reached a acceptable level the AGV was allowed to tested during production. At this stage numerous situations came up that the AGV could not yet handle. The most concerning ones are described in section 4.4. These situations appeared to come up quite often when the AGV was tested in the production. All these risk must strictly be dealt with before the AGV fully can be implemented.

5.2 Method criticism

The course of action taken for the methodology of this thesis was designed to enable a wide variety of inputs alongside solid credibility. The methods used where mostly drawn from Björklund and Paulsson [2012] Ovidijus [2014].
A problem in regard of conducting different forms of observations and benchmarks was that were no similar workflows to observe or compare with at Volvo Trucks in Gothenburg. The type of AGV that was used in this research was not implemented at any other place in the factory. This limited the ability to conduct informative internal benchmarks and direct observations. A good idea in hindsight would have been to find another company which used this type of AGV. Maybe an opening had presented itself to make a study visits where a functional benchmark, described in section 3.3.2.2, could have been made.

The education background of the authors was mechanical engineering at bachelor level. This background did not equip the authors with any sufficient computer programming skills in languages like Java or Python. Therefore, no deeper level of programming could be made which possibly could have included re-programming the core software for AGV. With competence in Java or Python it might have been possible to program the AGV to perform more advance tasks and modify several settings manually, without consulting the manufacturer.

Due to time limitations, the capability tests could not be held as they were instructed in the corporate standard Backman [2006]. The tests were required to be performed during a period of at least 8 hours straight for several days in a row during full production. The tests done in this study were only performed during 4 hours straight, two days in a row. However, the results gained could still give an indication for what an exact set of results could look like.

6

Conclusion and Recommendations

This chapter includes three parts. The first one answers the questions formulated in the first chapter. It also assesses some of the main results of this chase study. The second part focuses on providing a few recommendations for further development and research. These are based on the empirical findings and the questions answered in this conclusion. Finally, the third part provides a closing generalization.

6.1 Questions answered

This case study was aimed to answer a set of questions regarding the possibility to automate the delivery of material by an automated guided vehicle at Volvo Trucks in Tuve, Gothenburg.

RQ1: Is it possible to get the given AGV to work in the production at this point?

The short answer to this question is: no, the given AGV, model MiR200, cannot be implemented in the given production area at this time. This conclusion is based on the empirical findings and their analysis. The capability tests revealed that the AGV did not perform well enough to meet the standards that are set for new tooling an equipment.
There are four main hurdles that hinders the possibility to implement the AGV at this point: Unstable docking procedure, problems with "relative move", lack of rules for surrounding workflows and finally the lack of a functioning I/O module.

RQ2: How can the level of automation within the internal material handling be increased?

The LoA can be increased by successfully implementing the AGV to enable automated delivery of gearbox beams.
A few different missions were programmed and evaluated in section 4.5. Mission 3 presented the highest LoA that this research produced. It decreased the workload for truck driving operators and could run with minimal inputs from operators at the assembly line.

RQ3: How is a MiR centered workflow designed in a safe way?

In order to ensure a safe working environment around the AGV there needs to be a clear set of rules for surrounding traffic and people. This includes ensuring that the pathway is free from various details laying on the ground and to eliminate other trolleys to accidentally roll out in the pathway.
The camera needs to be replaced with a new one to ensure a safer work environment. This upgraded camera must be capable to cover a wider field of view. It needs to detect obstacles both below 50mm and above 995mm.

RQ4: What are the benefits of AGV automation compared to older and manually operated workflows?

The empirical findings showed that the AGV occupied a smaller amount of time when operating in the pathway compared the current workflow. One reason for this was that the AGV picked up the loaded trolley and left of the empty trolley within the pre-assembly area. The current workflow conducts these operations in different pathways throughout the production. Thus, taking up space in areas with heavy traffic.
Another benefit of implementing the given AGV is to increase the knowledge and competence within the company regarding automated deliveries of material. This could become an important asset for further implementations throughout the organisation. Both in Gothenburg as well as globally.
The AGV could unfortunately not be tested thoroughly enough in production to draw any conclusions regarding any potential economic benefits. I.e., this case study did not fully succeed to answer this research question.

6.2 Recommendations

In order to achieve a successful implementation of the AGV at the given location a few steps are recommended to be taken. Recommendations to achieve a higher level of automation are also included.

- *Docking procedure:* It is important to ensure a secure docking procedure that eliminates any errors. A breakthrough finding regarding the docking procedure was made at the end of the case study when all tests and evaluations had been made. It was discovered by changing the key setting "parameter for driving more straight during docking" to a very low value, 0,01. But there is still room for improvement on this point.
- *Relative move:* A software update made by Mobile Industrial Robots is recommended to be made regarding the action "relative move". This action is recommended to copy the approach of the normal "move" action. I.e. when an obstacle is encountered during a relative move the AGV should stop, wait for 5 seconds and then repeat this procedure a desired number of times. When this number has been exceeded the AGV should throw a normal error. This error can be taken care of using try/catch-programming. Thus, a

software update like this would increase the capability of the AGV in a great way.

- *I/O modules and sensors:* To increase the LoA it is recommended that further research is made regarding I/O modules and sensors. Pressing iPad buttons at the main manufacturing line is not a sufficient approach. It presents to many possibilities for failure.
  Therefore, it is recommended that the buttons on the I/O modules are designed and updated in such a way that they can set PLC-registers. It is also recommended to discover the possibility of using some sort of laser sensor. These should be used to detect if the gearbox beam has been lifted of the trolley. The sensor would then give a constant input signal that could easily be registered by the mission code for the AGV.
- *Modification of trolley:* When examining the trolley in figure 4.9 one can spot two red handles on each side of the trolley. These handles stick out approximately 4 cm on each side of the trolley. If they are not closed, they stick out even further. When conducting tests in the production it was noted that this handles sometimes got stuck in various obstacles.
  Based on these findings it is recommended that these handles are re-designed to obtain a smaller footprint. This would decrease the risks for accidents.
- *Increased automation:* Mission 3 was the program used for the AGV when tests were made in the production flow. When the shifts ended for the day or went on a break they had to press a button which told the AGV to charge. They also had to tell the AGV to continue its operation by pressing the button when the break was over.
  In order to increase the LoA it is recommended that a software update is made. This update should enable the AGV to be programmed based on the actual time. It should be made possible to program the AGV to charge for a desired time at different time points throughout the day.
- *Clear rules for surrounding workflows and traffic:* To ensure a safe work environment and to successfully implement the AGV a set of clear rules must be made. They are recommended to include rules for other truck operators which states who is precedent in different situations. It is also recommended to build safety barriers on the side of the pathway where the AGV is set do drive. This should be done to ensure that no other trolleys, details or fixtures happen to roll out in the pathway. Especially at a level higher than 950mm. If that happens there is a great chance for a severe accident.

6.3 Closing generalization

Since the beginning of this project it has been thought of as a case specific study. It was conducted at Volvo without any aim to generalize any conclusions. This paper was developed to produce results that were specific for Volvo, at the given production site.
However, when the empirical findings were analyzed it was made evident that the

conclusions made could be valuable in other cases. Thus, the results and conclusions presented in this study could probably be of use for other similar autonomous implementations internally at Volvo Trucks. They might also provide helpful information or function as a guideline for other organizations who explores new autonomous solutions which involves a similar type of AGV.

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A
Appendix 1

```
Mission 1: X1 hämta balk line:

If (PLC register 29==1)
 Relative move X=0.4, Y=0 O=0
 Relative move X=0, Y=0, O=90
 PLC register 29==0
return

if PLC register 25==1
 Run PLC register for shelf (Mir)

Run Pick up variable förmontering start= 1, Pick upp= hämta-
balk-farb, PLC25=PLC25+1

PLC register 29=2

if PLC register 28==0
 loop
  if PLC register 28==!
   PLC register 28=2
  break
  if pending mission >=1
  Return
  wait= 4


run place variable line: start= 2, place= 2, PLC25=PLC25+1
PLC register 28=2
run pick up variable line: start=3, pick up= 1, PLC25=PLC25+1
run place variable farb: start= 4, place= lämna-tom, PLC25=1
PLC register 29=0

if PLC register 28==1
 PLC register 28=1
 else
 PLC register 28=0
```

Figure A.1: Mission 1

```
Mission 2: X4 Hämta balk line:

loop
 if PLC register 25=1
  run: PLC register for shelf
 end

 run: pick up variable farb: start=1, pick up=hämta-balk-farb,
PLC25=PLC25+1

 loop
  if PLC register 31==1
   run: place variable line vänster: start= 2, PLC25=PLC25+1
   PLC register 31=1
   break
  end
  if PLC register 31==2
   run: place variable line höger: start= 2, PLC25=PLC25+1
   PLC register 31=1
   break
  end
  wait=4
 end

 loop
  if PLC register 31==1
   run: pick up variable: start= 3, pick up= 2, PLC25=PLC25+1
   PLC register 28=0
   break
  end
  if PLC register 31==2
   run: pick up variable: start= 3, pick up= 1 PLC25=PLC25+1
   PLC register 28=0
   break
  end
  run: place variable farb: start= 4, place= lämna tom,
PLC25=1
 end

 if PLC register 28==1
  PLC register 28=1
  else
  PLC register 28=0
 end

 if pending missions >=1
 return
end
```


Figure A.2: Mission 2

Mission 3: X6 Hämta balk Line

```
loop
> loop for 1 iterations
>> if PLC register 25 == 1
>>> run: PLC register for shelf
>> end

>> run: Pick up variable farb: start=1, pick up=Hämta-
   balk-farb, PLC25=PLC25 + 1

>> if PLC register 25 == 2

>>> loop
>>>> if PLC register 31 == 1
>>>>> run: Place variable Line: start=2, place=VL-
      marker line position 2, dock=VL-marker line
      position 2, PLC25=PLC25 + 1

      set PLC31=2
      break
     end

>>>> if PLC register 31 == 2
>>>>> run: Place variable Line: start=2, place=VL-
      marker line position 1, dock=VL-marker line
      position 1, PLC25=PLC25 + 1

      set PLC31=1
      break
     end

>> loop
>>> if PLC register 25 == 3
>>>> loop
>>>>> if PLC register 28 == 1
       break
      end
>>>>> if pending missions == 1
       play sound
       relative move: x=-2.4, orientation=90
       set PLC25=4
       set PLC33=1
       return
      else
       wait for 5 seconds
      end

>>> if PLC register 31 == 1
>>>> if PLC register 25 == 3
      run: relative move line: rotation 1=90,
      rotation 2= -90
     end

>>>> if PLC register 33 == 1
      wait for PLC28 = 1
       loop
```


Figure A.3: Mission 3 part 1

```
>>>>>>> try/catch
         try
          move to entry position related to: line
          position 2

          break
         catch
          play sound
          relative move: x=-2
          wait for 15 seconds
        end
       set PLC33=0
>>>> end

>>>> run: pick up variable line: start=4, pick up=
     line position 2, PLC25=PLC25 + 1

     set PLC28=0
     break

>>>> if PLC register 33 == 1
      wait for PLC28 = 1
       loop
>>>>>>> try/catch
         try
          move to entry position related to: line
          position 2

          break
         catch
          play sound
          relative move: x=-2
          wait for 15 seconds
        end
       set PLC33=0
>>>> end

>>>> run: pick up variable line: start=4, pick up=
     line position 2, PLC25=PLC25 + 1

     set PLC28=0
     break

>> place variable farb: start=5, place=lämna tom,
   set PLC25=1

> if PLC register 28 == 1
   set PLC28=1
  else
   set PLC28=0
  end

> if pending missions == 1
   return
  end
```


Figure A.4: Mission 3 part 2

```
Mission4: I/o-module:

loop
 if PLC register 25==1
  run PLC register for shelf
  PLC25=PLC25+1
 end

 run pick up variable farb: start=2, pick up=hämta-balk-farb,
PLC25=PLC25 +1

 if PLC 40==1
  run place variable: start=3, place= 1, PLC25=PLC25+1
 end

 if PLC 41==1
  run place variable: start=3, place= 2, PLC25=PLC25+1
 end

 wait for I/o device 42 to become ==1
  loop
   if PLC register 40=1
    run pick up variable: start=4, pick up= 2, PLC25=PLC25 +1
    PLC register 40=0
    PLC register 41=1
    break
   end
   if PLC register 41=1
    run pick up variable: start=4, pick up= 1, PLC25=PLC25 +1
    PLC register 40=1
    PLC register 41=0
    break
   end
  end
 end

 run place variable farb: start= 5, place= lämna tom, PLC25=1
end
```

Figure A.5: Mission 4

Sub mission: Place variable line

```
while: PLC register == “variable: where to start”
> if PLC register 26 == 0
>> if PLC register 26 == 0
    play sound: beep: custom length
    wait for 1 second
    PLC: register 26: set 1
  end
>> while: PLC register <= 3
    loop
     try/catch
      try
       move to entry position related to “variable: place VL marker”
       break
      catch
       if PLC register 50 == 1
        play sound: beep: custom length
        relative move: X = – 1
        wait for 15 seconds
       else
        wait for 15 seconds
       end
    end
    try/catch
     try
      dock to: “variable: dock”
      PLC: register 12: set 0
      place shelf: current position
      PLC: register 25: “variable: add/set”: “variable: plc value”
      relative move: X – 0.2
      break
     catch
      relative move: X – 0.5
      adjust localization
      PLC: register 26: add 1
       if PLC: register 26 => 3
        play sound: beep: full length
        move to entry position related to: “variable: place VL marker”
       end
       if PLC: register: 26 => 4
        throw error: something is blocking
        move to entry position related to: “variable: place VL marker”
end
PLC: register 26: set 0
```