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Challenges of using autonomous drive technology for autonomous transports in car manufacturing

Master's thesis in Production Engineering

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Department of Product and Production Development
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Abstract

Autonomous Drive technologies for self-driving cars have advanced to be one of the most important innovations within the automotive industry during the last couple of years. The customer and society benefits of Autonomous Drive are many, such as increased safety, reduced fuel consumption and more efficient road systems. However the Autonomous Drive technology might be beneficial in other areas as well.

The study presented in this master thesis is a part of a project at Volvo Cars, in which possibilities of using Autonomous Drive Technologies for Autonomous Transports in car manufacturing, are studied. Autonomous Transport is a new term at Volvo Cars that describes the use of Autonomous Drive technology for other purposes than the end customer. In this study, AT is defined to be a combination of the two existing technologies Autonomous Drive and Automated Guided Vehicle.

In the end of the car manufacturing process, the current intern logistic consist of operators driving the finished vehicle between test stations by an driver. This study focus on investigating the challenges with using Autonomous Transports in this part of the production, instead of a driver. The overall purpose is to increase the knowledge about this new transportation at Volvo Cars and take the first step towards this is by identifying the main issues of Autonomous Transports in car manufacturing.

The main part of the investigation is done as an empirical case study at Volvo Cars. Volvo Cars's production system and a group of employees from five different departments, with expertise within areas related to the study, have been the base when collecting data. The data have been gathered through interviews with practitioners, observations of the production system and from documents. A literature study was also conducted to provide the background information needed to design the empirical study.

The main outcome of this thesis is seven key issues covering the challenges with using Autonomous Transports in car manufacturing. An evaluation of what issues are most important, analyzes of the issues in relation to theory together with recommendations for the future work are provided. Overall, it can be concluded that Volvo Cars have to handle and further investigate the findings presented in this thesis in order to develop and assess solutions for efficient use of Autonomous Transports in car manufacturing.

Keywords: Autonomous Transports(AT), Autonomous Drive(AD), Car Manufacturing, Intern Logistic, Autonomous Guided Vehicles(AGV), Self-Driving Cars, Production Optimization, End of Line(EOL), Vehicle Testing, Volvo Cars Corporation

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Abbrevations

AD - Autonomous Drive

AGV - Automated guided vehicle

AT - Autonomous Transport

CAN - Controller Area Network

ECU - Electronic Control Units

EOL - End of Line

FAP - Fully Autonomous Parking

FC - Factory Complete

GPS - Global Positioning System

LIN - Local Interconnect Network

LPR - local Positioning Radar

MOST - Media-Oriented Systems Transports

RQ - Research Question

SIS - Swedish Standard Institution

Contents

1 Introduction

In this study the challenges of using Autonomous Drive (AD) technology for Autonomous Transports (AT) in car manufacturing have been investigated. The introduction section includes background; definitions of AD, AGV and AT; purpose & research questions and delimitations connected to the study. In section 1.4 Structure of Thesis, page 3, a holistic view of the study i provided.

1.1 Background

In the near future, car manufacturers will produce and deliver cars with Autonomous Drive (AD) abilities to customers. In Gartner's 2015 Hype Cycle, autonomous vehicles are shown to be on the peak, meaning that the technology is the current focus of attention for automotive companies [25]. AD technology is considered to be the next trend within automotive industry [5] and is forecasted to have a broad market applicability within 5-10 years [25]. Currently, most of the automotive OEMs over the world, such as Volvo, Daimler, BMW, Audi, Ford, Nissan and Volkswagen, are working with development projects focusing on the AD technology [5].

The Swedish automotive company Volvo Cars is a key member in a project called Drive Me. The Drive Me project is aiming to study the social benefits of AD, such as safer roads and lower CO2 emissions, and the project will have 100 autonomous cars driving on specific roads in Gothenburg by 2017 [62]. The AD technology will make it possible for the driver to just relax and read the newspaper while the car is in autopilot mode [62]. Even though the AD cars in the Drive Me project are able to drive by itself, it can only do so within specific areas and under specific conditions. The AD car in the Drive Me project will also require a driver that can take control if the situation becomes too complex for the car.

The benefits of AD technology are many. Some of the customer benefits are increased safety and the convenience and freedom of choosing what to do during the travel time. Some of the society benefits are a more efficient traffic system and less environmental impact due to lowered fuel consumption [7]. However the AD technology may be beneficial for other areas as well. A project called Born to Drive was initiated in the end of 2015, focusing on the outbound logistics benefits of using AD technology at Volvo Cars. Born to Drive aims to demonstrate the sequence of shunting cars from the point where they leave the factory to the loading location for truck transportation by using AD technology. However, the AD technology might entail benefits within the car manufacturing as well. In the factory there are a lot of transportation of the cars and currently this is done by operators driving the cars. This intern logistic might be possible to improve by using AD technology instead of an operator. The study presented in this thesis is a parallel study to the Born to Drive project, but are focusing on the manufacturing benefits of the AD technology.

Earlier work specifically investigating the possible benefits of utilising AD technology for transporting vehicles in car manufacturing has not been found. However, similar projects and technical solutions related to this study have been found. In the Drive Me project one part is to investigate the possibilities of fully autonomous parking (FAP). A demo car was developed to safely park itself in a parking lot while interacting with both non-autonomous vehicles and unprotected road users [12]. This was done by using the sensors on the car and combining AD with detection and auto brake for objects [12]. The self-parking project have several similarities with this study since the AD car is used within an environment similar to the factory environment, interacting with both objects and humans. Another similarity is the low speed on the parking lot as well as in the factory.

Using an AD car transporting itself at low speed in a car manufacturing environment is relatively similar to the use of AGVs. An example of an AGV used together with cars is the AGV developed for parking and arranging vehicles at an airport [40]. The AGV picks up the car and transports it to the right position. This means that any car, not just a car with a high technological level, can be transported without an operator. This solution may be applicable for transporting finished vehicles within car manufacturing as well, for example between two assembly lines [40]. This AGV however requires that there are no mixed or crossing traffic [40]. Another similar application area is the use of Autonomous Orchard Vehicles within fruit production companies [8], [29]. Here a car is rebuilt and equipped with systems giving it the ability to drive by itself so that the vehicle becomes an AGV. The vehicle is then able to navigate within a limited area without a driver.

1.1.1 AD - Autonomous Drive

AD is a technology allowing vehicles to take own decisions based on inputs from the surrounding environment. There are six formal definitions of levels of automation for AD cars and the three highest levels allows the vehicles to drive without human intervention in varying degrees. The higher level of automation, the more sophisticated technology in the car. At the highest level of automation the vehicle is fully autonomous meaning that there are no longer a need to have a steering wheel or pedals. The near future AD cars investigated in this study (Level 3, see section 3.3.2 Definition of Level of automation, page 20) will require a driver to intervene when the environment is unknown or in complex situations such as during bad weather conditions. An AD car have several different namings such as self-driven car and autonomous ground vehicle but in this thesis the term AD is constantly used.

1.1.2 AGV - Autonomous Guided Vehicles

An AGV is a driverless vehicle often used for intern logistic, for material handling, and are mostly used within manufacturing industries. The AGV drives totally automatically and can, in a safe way, be used in environments where humans are working. There are many different types of AGVs and they differ in size, speed, navigation system and how to perceive the surrounding environment.

1.1.3 AT - Autonomous Transports

The term AT is a new term used at Volvo Cars for AD technology utilized for other areas than at the end customer. There are no formal definition of AT yet but in this study AT is defined to be a combination of the two existing technologies AD and AGV, see Figure 1.1.

With the exceptions of having no driver, different environmental prerequisite and low speeds, AT is relatively similar to an AD car. AT have similarities with an AGV since it will be used for material handling without a driver. AT can therefore be seen as an AD car acting like its own AGV.

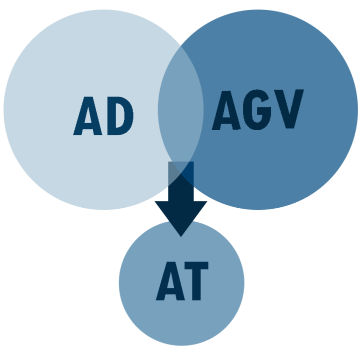

Figure 1.1: The Definition of AT is based on AD and AGV

1.2 Purpose & Research question

The purpose of the study is to increase the knowledge at Volvo Cars about the possibilities of using AT within the car manufacturing and to take the first step towards this by identifying the main challenges represented by a list of Issues . Therefor the research question of this thesis is: *What are the main challenges of using AT in car manufacturing?*

1.2.1 Issue

In this thesis, an issue is described as a problem area setting the baseline for further work (e.g., formulating problems and solutions). An issue can, for example, be a restriction or a prerequisite that needs to be handled.

1.3 Delimitations

The empirical study is only based on one case study performed at Volvo Cars Torslanda plant. The focus area for the case study is the EOL area in the assembly plant and the study is delimited to only cover the main production flow.

1.4 Structure of Thesis

The structure of this thesis is presented in Figure 1.2. Above, the introduction to the study was presented. Chapter 2 Methodology presents the methods used to answer the research question. Both a literature study and a case study have been conducted with several sub methods. The findings from the literature study are presented in Chapter 3 Theoretical Framework and the findings from the case study are presented in Chapter 4 Empirical Study. These studies have generated challenges i.e. issues of using AT in car manufacturing. A list of the main challenges found in this study are presented in section 4.7 Issue presentation, page 38, together with a prioritisation of the issue's importance in section 4.8 Prioritisation results, page 39. These issues and other parts of the study are further discussed in Chapter 5 Discussion. The conclusions of the study is presented in Chapter 6 Conclusion.

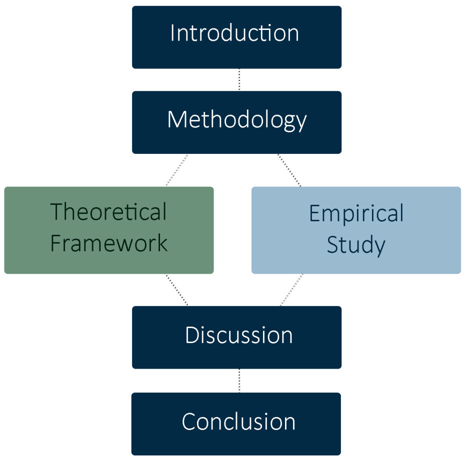

Figure 1.2: Structure of thesis

2 Methodology

This section describes how the study have was conducted and presents the methods used for answering the research question. An overview of the different methods is presented in 2.1 Research design. This is followed by theoretical background of the methods and a detailed description of how the methods have been used in this study.

2.1 Research design

The study consist of two main parts, the literature study (2.2 Literature study, page 5) resulting in the theoretical framework (3 Theoretical Framework) and the empirical study (2.3 Empirical study, page 6) resulting in issues. The literature study and the empirical study have been conducted in parallel. The literature study was however initiated before to get some theoretical background knowledge, which was required for designing the empirical study, see Figure 2.1. A search for similar projects were conducted in the initial phase of the literature study and the fact that there were no other projects investigating AT in car manufacturing, was a motivation for using an empirical case study approach.

Figure 2.1: The relation between Literature and Empirical study

There are systematic approaches for empirical research and in this study a systematic approach have been used in combination with several sub-methods [23], this is presented in Figure 2.2 where the blue boxes represents the systematic approach and the grey boxes represents the different sub-methods. This approach in combination with the background knowledge from the literature study has been the base when planning, designing and conducting the empirical study. For all steps in the empirical research, it was important to consider the validity of the study [23], this is further done in section 5.5 Validity evaluation, page 51.

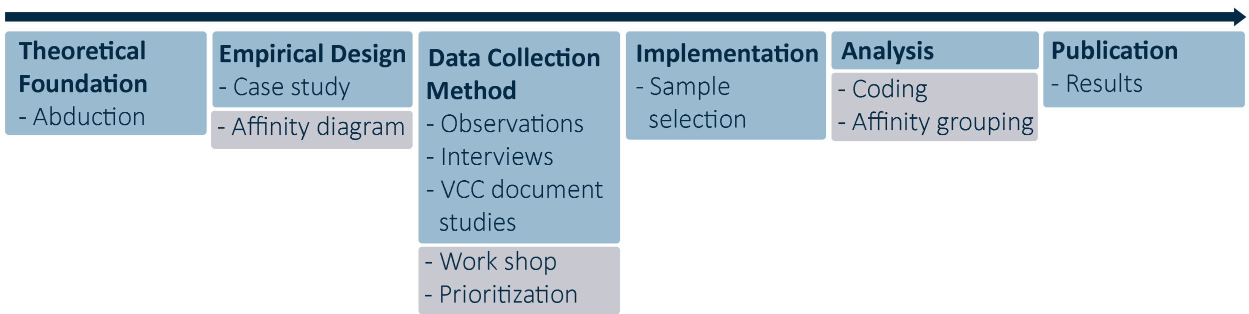

Figure 2.2: Overview of the Empirical study

As stated above, this study is a combination of theoretical and empirical studies and is based on abductive reasoning as theoretical foundation. Abduction means combining the two logical reasoning methods deduction and induction [21]. Deduction is when having a hypothesis and finding data, such as theory or observations, supporting the hypothesis [21]. Induction is when a hypothesis is built from theory and observations [21]. Using both together gives an opportunity to move back and forth from theory and observations to hypothesis and vice verse during the study.

A case study at Volvo Cars was chosen as the empirical study. The case study was based on the affinity diagram methodology. In the case study, interviews and observations were chosen as data collection methods in combination with the two sub-methods work shop and prioritisation. Executing a qualitative research with high quality requires experience and training [30]. The researchers in this study is not professionally trained in qualitative researches but have performed samples of qualitative research in educational contexts. Because of this, the qualitative data collection will follow methods and guidelines to reach the highest data quality possible. For implementing the data collection, a sample selection of people from different departments were chosen to avoid bias [23]. For the analysis, the sub-method coding was used to translate the qualitative data which than was analysed based on the affinity diagram framework. Both methods from the systematic approach for empirical research and the sub methods are presented further down in section 2.3 Empirical study, page 6.

2.2 Literature study

The first part of this study was the literature study consisting of a literature review and an in-depth research. The literature review gave an overview of interesting topics and generated keywords for further literature review and for the in-depth research. The literature study mainly consist of internet research. The age of the articles was limited to 2006 since AD is a relatively new technology and due to the fast technological development within the area.

2.2.1 Literature review

The purpose of a literature review is to understand what is already known within the area and to get an insight of useful theories, methods and strategies to use in a project [11]. When collecting information for a literature review, it is important to be critical to sources and biased authors and to compare different findings for validation [11]. Internet researches should preferable be executed in a systematic way to secure that all relevant articles are covered [11]. It is recommended to use different search motors and to identify as many useful keywords as possible [11].

To gain background information needed to proceed, the literature review was conducted as an initial activity of the literature study. At first the review was focused on understanding terms and concepts and was later changed to more advanced searches. The literature review included relevant databases and a systematic way of searching in each database. The databases Scopus, Google scholar, Science direct, Summon, Emerald insight, IEEE and SAE was used. When searching for related articles the following keywords was used, both independently and in combination:

- Autonomous drive
- Car Manufacturing
- Car Production
- Automotive
- Autonomous Car
- Driverless Car
- Self-driving Vehicle
- AGV
- Intelligent Transports
- Finished vehicle handling
- Autonomous Transport
- Autonomous ground vehicle

From the start the first four key words, presented above, was used but during the literature review more key words were found and added to the search. The review from the Born to Drive project was also included to cover what excising information they had found. The findings from the literature review are presented in the background of this thesis, see section 1.1 Background, page 1.

2.2.2 In-depth research

A more focused research was also conducted. Because AT is a new definition it is not possible to find information about it. Therefore, the existing technologies AD and AGV were investigated in relation to to car manufacturing (EOL). AD and AGV were analysed in relation to each other as a representation of AT and EOL to get a general perception of how the area is usually used. The outcome of the in-depth research can be found in Chapter 3 Theoretical Framework.

2.3 Empirical study

To answer the research question, an empirical case study at Volvo Cars was performed. The case study made it possible to focus on concrete examples in specific contexts when investigating the challenges of using AT in car manufacturing. In this section all methods used in the case study are presented, first with theory and in section 2.3.7 Empirical study procedure, page 10 how the methods were used in the specific case study.

The methods presented are both methods for data collection and analysis. Since no studies where AD is used in car manufacturing were found in the literature study, the best available data were the experience and expertise from people working with areas related to the focus areas AD, AGVs and EOL. This is why interviews and observations constitutes the major part of the data collection in this study. The framework of Affinity diagram have been used as a base during the whole empirical study and they will be presented below in chronological order.

2.3.1 Affinity diagram

Affinity diagram is one of the seven management tools [9] and can be used when organizing a large amount of qualitative data, often in relation to one or several focus questions [42]. A focus question is often put as why or what obstacles or preventions there is to achieve something. Affinity diagrams can, for example, be used for verbal data such as brainstorming ideas, customer desires or people's opinions [9]. As the name reveals, it organizes the data into groups of affinity and focuses on associations rather than logical connection [9].

This method can be divided into three stages: The divergent stage where the different views of a problem are discussed in a creative way, the processing stage where the views, opinions or data is organized and the decision making stage where it is decided what problems are most important [9]. These three stages can be divided into an eight-step process working as a guide when doing the affinity diagram [42]. These eight steps are:

Step 1: Determine a Focus Question
Step 2: Organize the Group
Step 3: Put Opinions (or Data) onto Sticky Notes
Step 4: Put Sticky Notes on the Wall
Step 5: Group Similar Items
Step 6: Naming Each Group
Step 7: Voting for the Most Important Groups
Step 8: Ranking the Most Important Groups

An affinity diagram is preferably done by a group of six to eight people, who have some experience of working as a team [9]. The work session is often held during just a couple of hours and is based on the opinions or other data coming from the group [42]. The group writes down their thoughts or opinions on Post-it notes and puts them on a wall [9]. Next, all notes are gone through by reading and discussing them in its context to make sure all participants understands the meaning of the note [9]. If a note is unclear it can be replaced with a new note that better describes its meaning [9].

When all notes are understood and put on the wall the first step is to group the Post-it notes together as groups based on matching contents [9]. This should be done in silence to prevent discussions about for example the semantic meaning of words [9]. If some group member wants to regroup notes it is allowed to do so, in that way divergent opinions about the data will be discovered even without discussion [9]. When all notes have been grouped and none of the participants are changing the groups the first grouping session is complete. It is allowed to have groups consisting of just one note, than called "lone wolfs" [9]. A heading is put over each group that represents the notes under it, and in this part talking is allowed. This grouping session can then be repeated creating a hierarchy of contents with new headings [9].

It is possible to discuss the relations between the groups of post-it notes in the Affinity diagram by drawing arrows between the groups. Then the relations becomes visible in the diagram [9]. This part of the method can however be excluded since it is fully possible to extract relevant information from the Affinity diagram even without relation between the groups [9].

When all groups of Post-it notes are set with a descriptive headline the groups should then be ranked in order to importance [9]. Here it is important that the team understands each others perspectives since it have shown to give a more correct picture of the reality [42]. The team marks the headings in order of importance which gives a rating [9]. After this, a summary of the affinity diagram is established, concluding the results [9].

2.3.2 Interviews

Interviews is said to be the most widely employed qualitative research method [11]. There are two main types of qualitative interviews, unstructured and semi-structured interviews [11]. Interviews are often followed by transcribing and analysis which makes interviews a time consuming task [11].

In a totally unstructured interview the researcher prepares topics or just a few open questions to talk about [11]. The interviewee is then allowed to talk freely about the topic or questions and the researcher responds and asks unprepared sub-questions within the area of interests [11]. This method have characteristics similar to an ordinary conversation [11] and is sometimes described as a conversation with a purpose [30]. An unstructured interview can be held spontaneously, for example when conducting an observation or if a conversation leads to an interesting topic [24]. Unstructured interviews often gives a deeper understanding of social settings and the interviewee gets an opportunity to, in a more relaxed way, give his or her point of view [11]. However, during this type of interview the researcher is often not prepared in the same way and the researcher must be able to ask questions that are relevant to the research question [24].

In semi-structured interviews, the researcher have a prepared interview guide with questions [11]. The researcher may change the order of the questions and ask questions not included in the original interview guide if an interesting topic are picked up during the interview [11]. This type of interview can be interpreted as a conversation from the interviewee's perspective [30] but the researchers sticks to the guide and adds sub-questions. If a project have a fairly clear focus it may be better to have semi-structured interviews [11].

An interview guide for an unstructured interview can be a brief list of memory points [11]. For a semi-structured interview the interview guide should be a bit more structured but does not need to have fully written questions [11]. The level of structure in an interview guide depends on the type of interview, type of research question, the purpose of the research and what other studies are conducted in a project [30]. There are, however, some parts that should be included when preparing an interview guide for any type of interview. An introduction, opening questions, key questions and closing questions [30]. In the first part of the introduction the researcher typically make a short presentation of herself, the research question and the purpose of the research [30]. The interviewee should also be informed about confidentiality of the interview and the level of anonymity [30]. In the second part of the introduction, the first questions are asked to the interviewee, about age, educational level and background [30]. These questions both gives the researcher some context and gives the interviewee time to become more comfortable by answering simple questions about themselves [30]. The questions after the introduction are often related to the topic of the interview and the questions are thereafter more focused key questions [30]. The key questions are the central part of the interview and are designed to collect the core information related to the research question [30].

2.3.3 Observations

Observation is a method used for systematic analysis of people in their actual context [30]. An observation means watching, listening, questioning and recording people, their reactions, as well as noticing the surrounding environment [30]. It is a suitable method to get an introduction to a new topic of research and it can provide a contextual understanding when using it in combination with other research methods [30]. When an observation is to be performed it needs to be decided what and when to observe and also how the observation should be recorded [30].

There are two main types of observation, participant observations and non-participant observations [30]. In a non-participant observations the researcher is a complete observer and should blend into the background and not influence the observation at all [30], like a "fly on the wall". This method can for example be used when the aim is to investigate what people actually do instead of what they think they do [59]. To perform observations without influencing the situation can however be difficult in practice since the actual observation might be an influencing factor in itself [30].

Participant observations, or ethnography [11], means that the researcher is participating in the activities while observing [30]. A participant observation requires intense researcher involvement in the day-to-day activities [11]. To become a natural part of the day-to-day work and really understand the environment the researcher has to observe for a considerable amount of time in the context of interest [11][24]. To conduct a full-scale ethnography is therefore not always possible [11], due to lack of resources. In that case a micro-ethnography can be performed, only focusing on a particular aspect [11]. Participant observations and non-participant observations are forming the boundaries for the observation spectra but the researcher can in practice span from complete participant to complete observer [11].

Informal interviews is a method close to regular conversations and are often a complementing part of participant observations [24]. Informal interviews means that questions can be prompted both by the researcher and by individuals in the field without preparation [24]. An additional approach to observation is the walk through the spaces observation [30]. The method means that the researcher walks through the study area with a representative from the area [30]. The representative describes the area and activities in the area and the researcher is given the possibility to ask questions [30].

2.3.4 Coding

Coding is a way of structuring qualitative data with the purpose to find analytical paths through the data [11]. A code could be any fragment such as an event, interaction or comment that have occurred once or repeatedly in the collected data [11]. There are three main ways to code, open coding, axial coding and selective coding [11]. Open coding implies that you should have an open mind when forming the codes. Axial coding is a way to make connection between the codes that were set in the open coding and in selective coding a core theme is selected and all other coding is set with that as a base [11]. When using open coding, concept cards (a list of codes specifying the data source, organizational member and the actual incident, quotation, opinion or event) helps put together codes that relate to a particular theme. This group of codes is then called concept [11]. If the concept is found several times in the data it can be an indication of higher significance [11].

2.3.5 Work shop

A focus group can be gathered in a work shop to discuss or make decisions. To get reliable information about a specific area, it is preferable to invite people with different experience and expertise [14]. When the participants have different backgrounds and areas of knowledge, it leads to several different perspectives in the work shop. In a work shop, a range of views can be collected within a relatively short period of time [30].

The optimum size of a successful focus group is six to eight participants [14][30]. A group consisting people with different background that do not know each other from before tend to explain and describe their experience in a more detailed way since they are unsure of the other group members knowledge [30]. This is a benefit when having a work shop. The group constellation in a work shop have a large impact on the result and must be taken into consideration when analysing the result [14]. In a work shop there should be a moderator guiding the discussions and make the participants active and focused [11]. The moderator should do this without being too involved or expressing its own opinions, in order to not influence the participants [14].

Vernissage is a method that can be used in work shop sessions when the purpose is to have an open and relaxed discussion. The group of people are wandering around with the purpose to discuss informative paper sheets placed around the room [46], like in a vernissage. It is possible to discuss the information in an informal way and share thoughts and knowledge with other participants. During a vernissage the researchers should act moderator with the goal to involve all participants and focus the discussion on the subject [46]. This also gives an opportunity for the researcher walk among the participants and listen to discussion and for example ask the participants if they have any additional inputs [46]. A vernissage session works best when having between 10 and 30 participants and the session goes on for around 10 min [46].

2.3.6 Prioritisation

There are several prioritizing methods and scales for determining the importance of elements e.g. issues. The methods are suitable in different situations and these can be categorized into ordinal and ratio scales [4]. The least powerful of those two is the ordinal scale which shows the most important elements but not how important they are in relation to the other elements. An example of a method leading to an ordinal scale is dot orientation. This is a method showing what a group rate as highest but doses not say anything about the difference between the rating [46]. In dot orientation Each participant gets 2-4 dots in different colors to place on the elements they interpret as most important [46]. This method does not indicate what the participants think about the other alternatives and does not say anything about how the participants see the alternatives in relation to each other.

To get this kind of information Cumulative Voting leading to a ratio scale can be used [4]. In Cumulative Voting there is a method called the 100 dollar method that is often used for prioritizing requirements. The participants are given 100 imaginary units to distribute between the requirements [4]. It is important that the group knows all alternatives well before the voting [46]. It is also important that the participants do not see others results before they voted. In that case there is a risk that they modify their votes to get their desired result, for example put all their points on one requirement [4]. After the prioritisation the researcher have information about which are the highest rated elements and also the ratio of disrupted units.

2.3.7 Empirical study procedure

The goal of the empirical case study was to generate and define the challenges according to the RQ represented by issues. For collecting and analysing data in the case study, the framework of Affinity diagram, also called the KJ-method, was used. The framework of Affinity Diagram have however been adjusted and extended with additional methods to fit the study. In what order those methods were used and the outcome of each sub method is described in this section and is visualized in Figure 2.3. The steps below is the same steps as the ones presented in section 2.3.1 Affinity diagram, page 6. Because of the extension of the method it took several weeks to complete the Affinity diagram instead of a couple of hours, as it unusually does.

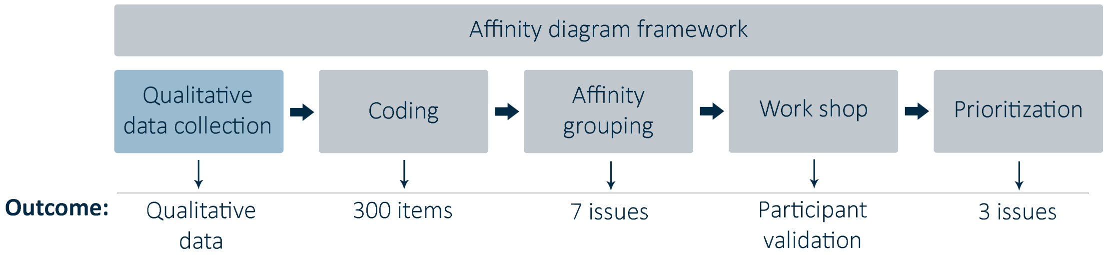

Figure 2.3: Sub method overview and outcome

Step 1, Determine a Focus Question: As a first step the focus question was determined. In this affinity diagram the focus question was aligned with the research question: *What are the main challenges of using AT in car manufacturing?*

Step 2, Organize the Group: Two groups were involved in this affinity diagram. The first group was two researchers designing the case study and analysing the data. The second group consisted of employees at Volvo Cars, representing five different departments and several different areas of expertise related to the focus areas, AD, AGV and EOL. The five different departments were used as a base when collecting data. The departments and the group from Volvo Cars is presented below:

R&D R&D is a large part of Volvo Cars where the research and development of the cars are conducted, a part of R&D is working with developing the future AD technology. Two representatives working with AD technology have been interviewed. The first interviewee was an AD expert with over 15 years experience of technical expertise within active safety and have knowledge about the requirements of future AD cars and how the systems in the car works. The second interview was held with a sensor expert working within active safety as a systems project manager, with a lot of experience from development of single components. When working with developing components, some industrialisation problems were a part of the work which means that this interviewee also had some experience from the production area, and in particular EOL area.

Logistics Within outbound logistics, two representatives from yard operations were interviewed, both at the same occasion. Outbound logistics are working with finished vehicle handling outside of the factory. They arrange the finished cars on the yard so the cars can be effectively transported to customer or retailer all over the world. Both of the interviewees are yard operation managers with different responsibility areas. The first yard operation manager had been working in the current position for half a year but have over 15 years experience from Volvo Cars working in the factory with manufacturing logistics. The second yard operation manager had many years of experience working within car logistic and have been working in the current position for the last three years. This department is one of the main stakeholders in the Born to Drive project and it is their process, handling the logistics on the yard, is the main focus of that project. Both interviewees were therefore well aware of the Born to Drive project.

Manufacturing The manufacturing department is working with preparing and developing the production for new product launches. Their main task is to balance the production prerequisites, to make the manufacturing as efficient as possible. Manufacturing engineers are experts in setting up requirements on processes and products and they are responsible for a specific focus area in the factory or a specific part of the car. A technical expert within the EOL processes area was interviewed. The technical expert had been working at Volvo Cars for 27 years and in the current position for more than 15 years.

Production To capture the production perspective, an interview was held with a technical expert from the production. The interviewee had overall expertise knowledge about the processes in EOL and had been working in the current position for 13 years. The production expert was previously working as a manufacturing engineer and had 22 years of experience within Volvo Cars.

Safety Safety is an important aspects when working in an environment where humans are interacting with machines like they do in a manufacturing environment. Due to this, a safety expert in Volvo Cars' factories was interviewed. The safety expert had nearly 30 years experience of working with safety and work environment and had been in the current position for two years.

Step 3, Put Opinions on Post-it notes: In this study the opinions and knowledge of the group, that is usually used as input in an affinity diagram, was represented by a qualitative data collection. Having the qualitative data from observations and interviews as input to the affinity diagram led to an extended and a more structured data generation with an increased level of details than what is usually used in an Affinity diagram. To gather the opinions of the group, mainly interviews and observations were used. Several interviews of different approach have been conducted. There have been unstructured interviews intertwined with observations and to get a broad perspective of the challenges of using AT in EOL, semi-structured interviews were also held. All semi-structured interviews were pre-booked, the interview time varied between 30-45 min and the interviewees were informed about the anonymity in the study.

Six persons from five different departments At Volvo Cars were interviewed with the same interview guide consisting of nine interview questions, see Appendix A on page 57. The purpose of having the same interview guide was to get different perspectives on the questions and to get as close as possible to areas related to the research question. The choice of participants for these interviews were therefor based on what departments would be involved or affected if implementing AT at Volvo Cars. The interviewees were employees at Volvo Cars, from the departments: R&D, logistics, manufacturing, production and safety as described in Step 2. After the five first interviews there were a missing link in the collected data regarding the sensor setup on future AD cars. An additional interview was therefor held with a technical expert from R&D, Active Safety. The last interview was also held with the same interview guide. The department involved in the interviews is visualised in Figure 2.4.

As a complement to the interviews there have been several observations in this study with different purposes. The initial observation was a walk through the spaces observation in Volvo Cars's Assembly shop. This tour was guided by the Volvo Cars supervisor who has expertise

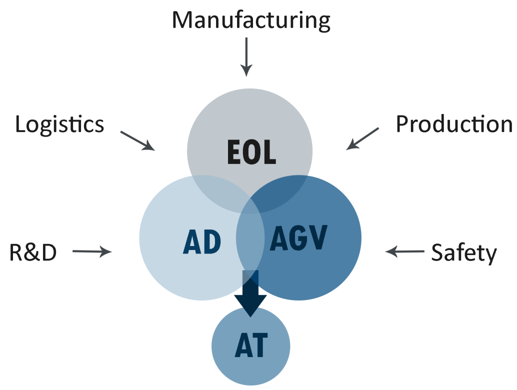

Figure 2.4: Focus areas and departments included in interviews

knowledge of the EOL area and especially the software download and configuration of the car. All parts were described briefly but more focus was put on the stations in the EOL. A continuous conversation was held during the walk and notes were taken. The purpose of this observation was to observe the flow and to get an holistic and brief introduction to the Assembly shop with focus on the EOL processes.

To get a deeper understanding and another perspective, an additional walk through space observation was held with the EOL technical production expert who has knowledge of the processes in the EOL area. During this observation additional information about the processes were given with a production perspective.

To further understand each process in the EOL, observations were conducted on all stations. Each station were separately observed during several working cycles, first with non-participation and later with operator conversation. During the non-participation observation notes were taken and questions were formulated about the station that that were not understood by just watching. Each cycle was observed at least five times to identify the cycle and reduce operator variation. After the non-participant observation the questions about the station were asked and answered by the operator. This observation method was applied on all after line stations within the EOL: Chassis Setting, Air Suspension Calibration, Wheel and Light Alignment, Radar Calibration, Roller Bench Test, Short Track and Final Health Check, see Figure 4.2.

To gain information about how Volvo Cars uses AGVs, two additional locations was observed, the Body shop and the warehouse at Volvo Cars. In the Body shop the walk through the spaces observation was used. The observation was guided by a safety expert at Volvo Cars with good knowledge about the different factories. The AGVs were watched in action and questions were asked. At the warehouse the AGVs were recently replaced by conveyor lines. The observation was therefore focused on understanding how the AGVs were used before. The purpose of these observation was to see the AGV in its context and understand how it was operated.

When an interview or observations were completed the data was continuously transcribed. After that, the transcripts were systematically open coded. Open coding was used as coding method since it allows the researcher to gather all kinds of items i.e. an extract from the transcript such as a word, a comment or an interesting sentence that in some way is related to the study. The coding was conducted by marking pieces of text that the researchers thought were interesting for the study, reacted on or were repeated several times by the interviewees. Each interview was coded in parallel by both researchers. The reason for this was to not miss important information and validate the importance of each item. When a text was coded the words and sentences were discussed and summarized on Post-it notes, one item on each note.

All items were transferred to Post-it notes and after the coding was finished, around 300 items, i.e. 300 Post-it notes were created. An example of a coded transcript and Post-it notes with items can be seen in Figure 2.5. Different colours of the Post-it notes were used to separate the information in the notes. For example the notes that were expressed as main issues from the interviewees had a specific color and the identified benefits of using AT in car manufacturing was given another colour. To make all information traceable to the interviewees each Post-it note was marked with a sign representing the interviewee.

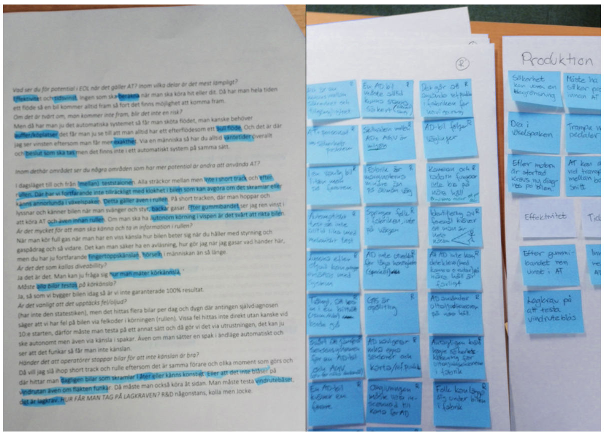

Figure 2.5: The transcript coding and items on Post-it notes

Step 4, Put Post-it notes on the wall: All items were randomly put a the wall and the researchers red each note out loud and clarified the meaning of it. If an item was unclear the Post-it note was clarified and rewritten.

Step 5, Group Similar Items - Step 6, Naming Groups: Without discussion, the researchers started to group the Post-it notes in groups of affinity. If the researchers did not agree with each other or saw other connections among the notes it was allowed to move and rearrange the them. After the fist grouping session all the groups were named. The names were written on a bigger Post-it notes and put over the group of affinity as a headline representing the specific group of affinity. If some notes in the group did not fit under the headline it was simply extracted from the group and added to another group. When the researchers were satisfied with the level 1 grouping. The small Post-it notes were clustered under the heading and the headings were then grouped in level 2 groups of affinity. The grouping (Step 5-6) was iterated until there was less than 10 different groups left on the wall. These were the groups represented the issues of using AT in car manufacturing. All issues were described in detail and some examples, from the Volvo Cars manufacturing context, were stated to ease the understanding of the issue. The issues are presented in section 4.7 Issue presentation, page 38 and further discussed in Chapter 5 Discussion

Step 7, Voting for the Most Important Groups: The prioritizing of the issues was done during a work shop. Representatives from four of the five invited departments were participating together with the supervisor at Volvo Cars. Most of the participant did not know each other from before. All people invited to the work shop were however not able to participate. From some departments, the representative was the interviewee and from some departments the representative was new to the study and without deeper knowledge about AT. Therefore, the project was presented in short to ensure all participants were aware of the purpose and RQ.

After this, a presentation with a short description of the issues, a picture representing the issue and concrete examples was used to explain the issues. The participants got the opportunity to comment and ask questions to make sure all participant understood the issues and how the researchers had interpreted it.

The next step in the work shop was a vernissage session to open up for discussion in a focused and structured way. A3 posters were put on the walls in the conference room, one poster for each issue. The posters contained the same information and picture as in the presentation, no new information was added. The purpose of the vernissage was to increase the understanding of the issues among the participants and to validate the issues. The discussion on each A3 poster was around 4 min and the discussion was very open to not influence the thoughts of the group. To increase the involvement of the participants, but still focus at one issue at a time, the vernissage was held standing up in front of the poster. The researchers worked as moderators during the vernissage to involve all participants and keep the discussion related to the issues. Green and red post-it notes was used during the vernissage to document input from the participants. These were used by the researchers to note general comments and agreements (green) or questions and disagreements (red). When a Post-it note was written it was put on the A3 poster so everyone could see it and reflect on it in the discussion.

After this the prioritisation session was started. A short presentation of the rating method was held before the participants started the rating. The task was to grade the seven issues by "importance" of what to focus on first based on industrial needs at Volvo Cars. Each participant got 100p to distribute on the 7 issues. High points represented high importance and low points represented low importance. 0 points meant no importance at all. The grading was done anonymously towards the rest of the group by forms that were handed in to the researchers.

After the grading the result were gathered and put into a prepared excel diagram. The diagram was shown to the participants and a short discussion about the result were held. At this point the participants were also asked if there was anything to add or if they could think of an additional issue. Two additional work shop sessions were held separately with representatives that was not able to participate in the work shop. In these sessions the researchers presented and discussed each issue and the participant graded the issues by importance.

Step 8, Ranking the Most Important Groups: The grading sheets from all work shops were gathered and filled in to an excel sheet. The data was presented in a bar chart, one bar for each issue. The disagreement of the rating was also calculated and shown as a line chart in the same graph. The result from the prioritisation is presented in section 4.8 Prioritisation results, page 39

3 Theoretical Framework

This section presents theory connected to the three focus areas, EOL, AD and AGV, see Figure 3.1. Since AT is a new term it is not possible to find information about, but the focus areas will provide theory as close to AT as possible. This section also covers general production methods used in car manufacturing, information on about how vehicles are developed and theory about standards and directives for further elaboration of how AT can be interpreted and defined.

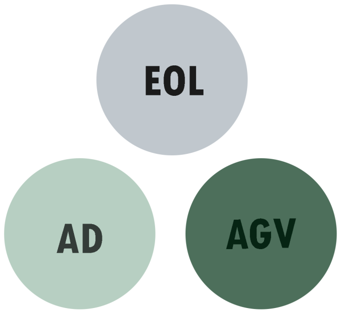

Figure 3.1: Focus areas in Theoretical Framework

3.1 Vehicle production

The production of a car starts after a customer have made an order with vehicle specification such as model type, colour, and features. Than the cars are build according to these configurations, which result in a large variety of products within the same production [64].

A vehicle production often consist of different steps where the car is processed in a specific sequence. Common processes are stamping, joining, painting, assembling and testing [50].

In the first process, metal sheets are cut and stamped in the production area called Body shop. Big stamps are used to mould parts to the vehicle frame such as the chassis, side walls doors and roof [64]. In the next process the metal sheets are built together. This can be performed both manually and automatic by employees and robots [64]. There are a number of different techniques for joining and some are laser welding, resistance sealing, MIG, MAG, folding, riveting etc. [64]. When the car leaves the Body shop the vehicle body has a grey finish and the next process is the painting.

Within the Paint shop the vehicle is treated with anti-corrosion protection. A thin layer are applied by immersion of the whole vehicle body in anti-corrosion protection [64]. Big tanks with liquid anti-corrosion protection are used for the immersion [64]. Robots are then used to apply protection on the chassis that seals, reduce noises and protects the surface [64]. The car is then painted with interlayer, basecoat and clear coat within different painting cabins and according to each customer's choice [64]. The operations can be performed manually or automatically by robots [64].

After this production step the car arrives to the Assembly shop. This area mainly consist of assembly lines, that includes the main line where the vehicle are build but also sub-assembly lines for components such as cockpits, doors and engine [64]. While the most of the manufacturing processes are machinery and material driven activities, assembling consist of more labour work [50]. The most operations are performed by employees which uses manipulators and fixtures to help positioning the parts and to ensure that the correct force is applied when the parts are fastened together [64].

Between the different production stages quality tests are performed [64]. In the end of the assembly plant the cars are tested for the last time before they are delivered to the end customer. This is the EOL area. The wheel angles are measured and adjusted, the tilt angle of the headlights are adjusted and the engine and brakes are tested in a Roller bench test [64]. When the last test is done the cars leave the factory to be delivered to the customers.

Toyota is a car manufacturer that have had a large impact on the production principles used in the automotive industry through the Lean production philosophy [38]. Lean production started within the automotive industry but now it is commonly used within almost all types of production industries [38]. Lean production involves philosophies such as have a continuous flow to detect problems, use a pull system to avoid overproduction and level out the workload [38].

A flow is when products do not have to idle between the work stations since the processes an people are linked together [38]. A flow helps detecting problems since a problem may result in a stop that will be visualised by an unwanted buffer. Operators in a pull system takes components from the previous work station when the work with the current component are finished. The down stream stations are therefor said to pulls the products through the system [1]. The term Heijunka means to have a stable workload [38].

Vehicle production often requires a control system to synchronize the production between the different subsystems and according to the deliveries of parts from internal and external suppliers [50]. The car is marked with a specific vehicle Identification number (VIN) in the beginning of the manufacturing process [64] and used for identifying the cars. Sensors are used to recognize and track the position of the car and other components, such as the fuel tank and power-train, through the manufacturing process [50].

3.1.1 Assembly shop

There are different types of production layouts such as fixed production, functional layout, batch flow and line-based flow [6]. The layout describes how the arrangement of the production and equipment are positioned. Which layout that suit each production process depends on factors such as the production volume and number of variants [6].

Most final assembly areas within vehicle production consist of production lines. Ford developed a moving assembly line in 1913 which was an important development step for the automotive industry [18]. The assembly lines allowed high-volume to a low cost [66] and it also made the manufacturing more efficient, resulting that the cars became cheaper and more people could afford to buy one [18].

The layout and placement of operations and machines are coherently depending on the precedence relationships [50]. Some machines, jigs and conveyors can be so called fixed points and limiting changes [50]. The workstations are arranged serially and the cars are moving between these in constant speed [19]. Hundreds of cars are at the line at the same time and are therefore processed simultaneously [18]. Within each workstations a number of specific tasks are performed and repeated on every car. When a car arrives the worker goes upstream on the conveyor belt and meet the car. During the assembling the operators are following the car by walking downstream along with it [19]. The time the operator are allowed to spend on the operations are ended when the car leaves the workstation [19].

The cars follows the main line while components and semi-assemblies are mounted onto it [50]. The main flow is the line where the vehicles are built but there are also other pre-assembly lines for big or complex parts such as the engine, the cockpit and the doors [64]. All different lines are than merged together, the doors and cockpit are assembled onto the main line. In the final assembly there often are cells for pre-assemblies that is prepared to be assembled on the main line [50]. Many parts are also ordered from suppliers and are delivered as delivered units [18]. The material within the final assembly are often transported by autonomous guided vehicles (AGV) or conveyor systems [50].

The Assembly shop area contains both automated and robotic stations but consist mainly of manual assembly work [50]. Axles, drive shafts, tanks, suspensions and wheel drums are some components assembled within the final assembly [43]. For the manual assembly work fixture power tools and manipulators are commonly used to help operators lift heavy components, positioning the parts and ensure the torque for joints [64]. It is important that human and machine can interact in a safe and ergonomic way [50].

Ford had a strategy that steady, repetitive productions reduces costs [60]. It is important that the work is standardized to ensure that the same process is repeated and that the same amount of time is consumed, this can be done by work standards and time studies [50]. The production line have been commonly used within the automotive industry since it was developed by Henry Ford and the principles of modern production lines have not changed much since than [18].

One drawback with the production line is a consequence of the repetitive tasks. The operations can be boring and extremely repetitive and the workers can feel uncommitted and that they have no ownership or impact on the products they are building.

There are different losses connected to a assembly systems such as handling losses and balancing losses [6]. Balancing losses is of extra importance within assembly line systems [6]. The work content and required operation time within the different work stations must be evenly distributed to minimize balancing losses [6]. If the time differs a lot the balancing losses will be higher since some operator will have unnecessary time that is non value adding.

In the automotive industry the customers have a large number of options about design and functions. The customer can choose between several different engines, colours, wheels, comfort items, technical and electric functions which leads to a high variety of operations on the assembly line [19].

A mixed model production handles several different products on the same line without a need for changeovers [60]. The mixed model assembly lines are flexible since a variation of cars can be built concurrently [39]. This production strategy is common within the automotive industry because it is a way to handle diversification of the customer's demands to a relative low cost [39]. Mass customization aims for combining low unit cost due to mass production and at the same time make the products individual [19]. Mixed model lines can be used for this.

The characteristics of a mixed model assembly line partly correlates with the Lean production philosophies. It is a continuous flow with a pull system but to even out the workload is more problematic. The challenge with mixed-model assembly lines are to develop a successful strategy for the logistics of parts and workload for the different workstations since this varied depending on the sequence of cars [39].

When the assembly of the car is completed, the car comes of the line. The next phase is to test the car in the EOL area.

3.1.2 End Of Line testing

Several tests are performed during the manufacturing processes but within the EOL area final test on complete cars are performed in order to detect errors before they are delivered to the end customer [64], [28]. Vehicle recalls are costly for the automakers and final tests can reduce the number of complaints and make the customer more satisfied [28], [43].

The EOL area within an automotive manufacturing consist of adjustments and tests to ensure the quality of the car [58].

Different car manufacturers perform different tests but common tests within the automotive industry are brake test, engine drum test, headlight test, alignment tests for wheels and turning [50], assistance systems, chassis suspension [58], tire and emission tests [45].

In the wheel alignment test the wheels are manually adjusted to be in correct position with help of laser sensors [64]. The vehicle's driving condition, braking force and emissions can be tested within a chassis dynamometer test booth [50]. Underneath the floor in the booth are pairs of big rolls mounted, one pair for each wheel. When the car is in correct position it can accelerate and brake without moving physically. The driver is operating the vehicle according to a defined driving curve by following instructions. A water test can also be done in a drench cabin in order to control the seals and the construction [50], [64] [28]. The test is than performed within a drench cabin.

3.1.3 Robustness

A robust production system have the capability of either avoiding or handing disturbances in a successful way [6]. Production disturbances can lead to losses caused by, for example, equipment faults, interruptions, reduced speed, small stops and start-up losses or defects in the process [6]. These disturbances can bee seen from many different perspectives such as maintenance perspective, production perspective, quality perspective and security perspective [6]. When handling disturbances the best way is often found when considering all perspectives of disturbances [6] but in this study the focus lies on the production perspective.

In Toyota's factories the operators are encourage to stop the line if a problem are detected [38]. To stop the production is a disturbance and costly [18] but the benefits of solving the problem where it is detected, instead of letting it pass, are more effective.

3.2 Vehicle development

A vehicle development process maintains a high level of engineering complexity and involves many departments and project members [52]. The different activities within the vehicle development process is often done independently and the project tasks are either performed in parallel, sequentially or overlapping [52]. A development processes often have an overall business development process which evaluates new proposals and updates cycle plan of the company [52]. When a decision about starting new vehicle programs are made the development process contains of stage gates and checkpoint which is being followed up by the project management [52], these stage gates and checkpoints are shown in Figure 3.2. The management controls that the gate criteria for the current gate are met, prepares for the next gate and continuously updates the project final delivery prediction and associated risks within the project.

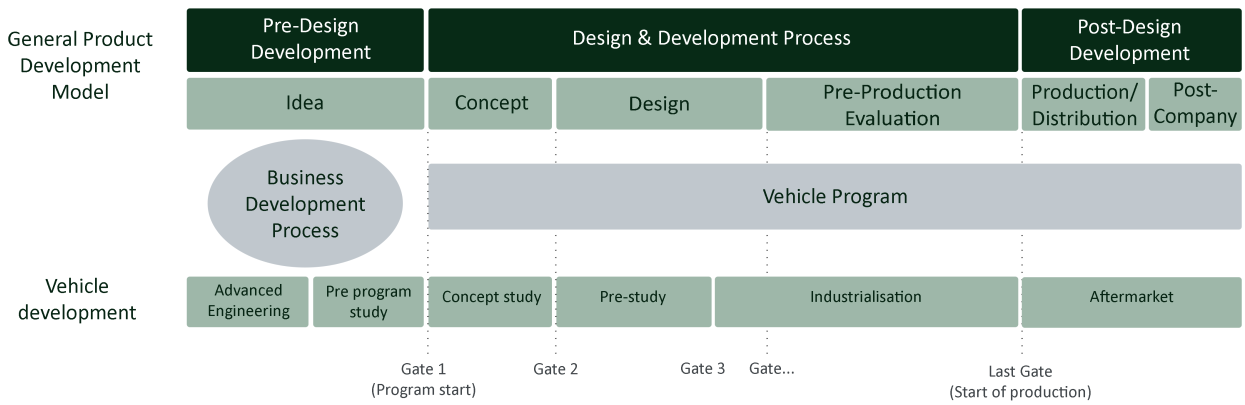

Figure 3.2: Product Development Models

A product development project generally follows specific phases. The first phase is the Pre-design development which starts with an idea. As mentioned above a new idea or proposal is included in the overall business development process which evaluates the idea and then perform feasibility studies [53]. In vehicle development, customer demands and market surveys are often incentives for new ideas. This is then followed by advanced engineering activities followed by a pre-study of the idea. If it is decided to go on with the idea the next step is the Design and Development phase [53]. This phase includes the concept stage, the design stage and the pre-production evaluation [52]. The concept phase converts the idea and business evaluation to a viable but conceptual solution that fulfills all requirements. Both internal and external requirements should be included and it should also support the production feasibility [53]. In the design phase exact parameters of the product are determined with regards to the requirements and limitations set in the conceptual stage. Here prototypes are made and tests are performed to make sure both physical requirements and production requirements are met [53]. The pre-production evaluation ensures that it is possible to produce the product. After the product is fully developed the Post-Design development phase starts. This includes both the production of the product, the delivery to the market and the progress after the product have left the company by monitoring issues such as complaints, sales and lifetime of the product [53].

The amount of electrical systems and software in cars are increasing rapidly making the complexity of the electrical systems and software functions continuously increase [52]. For the AD cars electrical systems and software will increase even further and it will affect the development process of the car [52]. In contrast to mechanical development software can be changed within short intervals in the development process and even when producing the vehicle [52].

3.3 Autonomous Drive

Autonomous Drive is the technology behind self-driving cars and have the potential to transform the commute, increase safety, improve fuel efficiency and road capacity [22] and therefore ease the urban mobility [31]. This section presents the development and future possibilities of AD cars but also how the sensors, the navigation system, the safety functions and the decision making system works.

3.3.1 The development of AD technology

The driving ability of autonomous vehicles have been rapidly developed during the past two decades [49]. There have been many test pilot projects of autonomous cars competing against other brands in specific competitions [49]. Some competitions are DARPA, PROUD, IVFC, VIAC and Hyundai Autonomous challenge [10]. These competitions are one factor pushing the development of the AD technology. The competitions have different approaches managing specific scenarios such as drive in urban environments or to drive a certain distance without human intervention [10]. Already in 2010 a vehicle were reported to be able to drive autonomously in a real urban environment successfully preforming lane keeping, adaption of distance and speed to the traffic flow, traffic light interaction and a U-turn on an intersection [49].

Elements of autonomy such as parking assistance, adaptive cruise control and automated braking exist in the cars on the market today [65]. Other systems such as lane departure avoidance and obstacle avoidance exist but is more rare. The near future AD cars will look like today's cars, with a drivers and a steering wheel [65] but it will be able to control parts of the driving itself. The next generation of AD cars will however require a driver able to take control if the situation becomes too complex, for example during difficult weather conditions.

Several companies such as Volvo, Google, Audi and Delphi have put their demo autonomous cars on the roads [48]. Drive Me is a project where the authorities, the industry and the academic community works together to develop the near future AD car. In the project Volvo Cars have a large role and they are aiming for initiating tests with cars driving on 50km of selected roads in the near future. The chosen roads are typical commuter roads and consists of motorway conditions and frequent queues [13]. This means that AD will only be available on the selected roads as a start and the driver will have to control the car when outside of the zone [13]. In the long term, it is likely that the zone limitation of AD will be gradually removed. If the situation becomes too complex the car will request the driver to take over. Volvo Cars will first launch 100 cars to customers and will then have a more broad roll out [3]. The Drive Me project also includes FAP without a drives in the front seat. The driver is allowed to walk away from the car while it is finding a vacant parking spot and does the parking by itself [13].

Highly automated cars performs dynamic driving task without human intervention [57] [33]. Dynamic driving tasks are operations such as accelerating, steering and braking but also to determine when to use signals, turn or change lane [57]. The vehicle uses advanced technology for sensing it's dynamic environment to be able to make real-time decisions without human intervention [33]. When the car are fully automated and have the total control it can result in large benefits for both individuals and the society. Members of IEEE predicts that by 2040, autonomous cars will consist of up to 75 %. of the cars on the roads [32].

3.3.2 Definition of Level of automation

There are many definition for autonomous and self-driving cars. To eliminate confusion, the definitions from SAE International [35] are being used through this thesis. SAE International is a global association with focus on, among other things, the automotive industry and provides internationally recognized standards within the field. One of the standards defines different levels of automation for vehicles. The level of automation is based on the drivers role and required intervention during the driving [57]. The levels span from no automation where the driver operates the car, to fully automated where the automated driving systems controls the entire driving. One main difference stressed in the SAE definition is who is monitoring the driving environment, the driver or the automated driving systems. At the lower levels 0,1 and 2 the monitoring is made by the human driver whilst in the higher levels 3,4 and 5 the cars will have total control of driving during specific circumstances [65]. The different levels are presented in detailed in the Table 3.1 and are summarized below.

Table 3.1: Level of Automation from SAE, [57]

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Level 0 - The human driver is performing all driving tasks [57].

Level 1 - The first level of automation consist of support within one dynamic driving task such as steering or acceleration [57].

Level 2 - Several support systems for the dynamic driving is available at this level [57].

Level 3 - The automated driving system is monitoring the driving environment and controlling the dynamic driving tasks but the human driver can get a request to intervene when necessary [57].

Level 4 - The cars will be able to drive by the use of the automated systems without require human intervention in specific driving environments and scenarios [57].

Level 5 - The automated driving systems will perform driving in all kinds of environment and scenarios with no need for the driver to intervene [57].

3.3.3 Sensor setup

An AD vehicle have three main technological elements: Sensors to register and scan the environment, computers that handles information to make decisions and actuators for controlling the vehicle [41].

There are many different sensors in an AD car. Some sensors are used to get data about the car's speed and direction [51]. Sensors to perceive the environment around the AD car is needed to detect the road, lanes and obstacles on the road such as other vehicles and pedestrians [33]. For an AD system used for high speeds and long range there are up to nine cameras, nine radar sensors and a laser system [3]. In the windscreen of the car, there is a camera and a 76 GHz frequency-modulated wave radar. This combination of camera and radar is able to detect and identify objects on the road in front of the car. In the windscreen there are an additional camera that works as three cameras in one, that are optimised to focus on different distances. One camera has a brad view of 140°and are optimised for short distances detection and one camera are adapted for long-range detection and has therefore a narrow view of 34°to improve the depth perception. There are also one camera that covers the distance in between and this camera has a view of 45°.

Four cameras are monitoring the lane markings and close to the vehicle two on the rear view mirrors, one in the front grille and one in the rear bumper [26], see Figure 3.3.

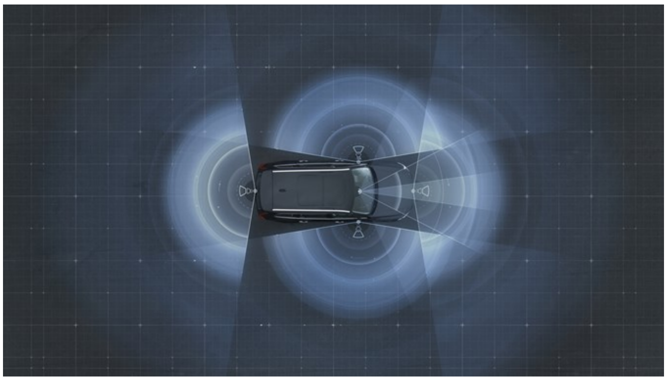

Figure 3.3: The cameras [26]

There are four radars behind the front and rear bumpers of the car, one in each corner. These radars are able to locate objects in all directions. In the rear of the car there are also two long-range radars to ensure a good rearward detection [26], Figure 3.4.

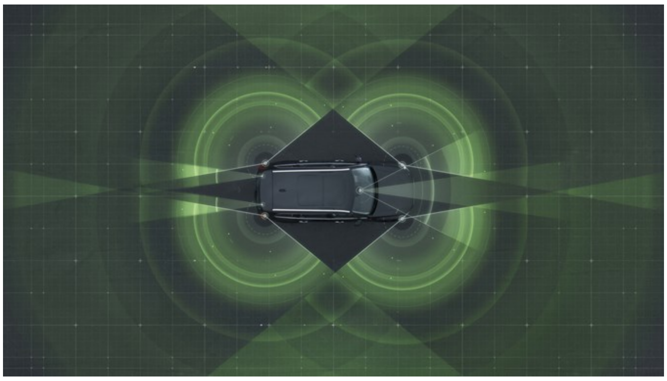

Figure 3.4: The radars [26]

The laser system can identify and distinguish between objects in front of the car within 150m and a range of 140°. This is done by a multiple beam laser scanner [27], Figure 3.5.

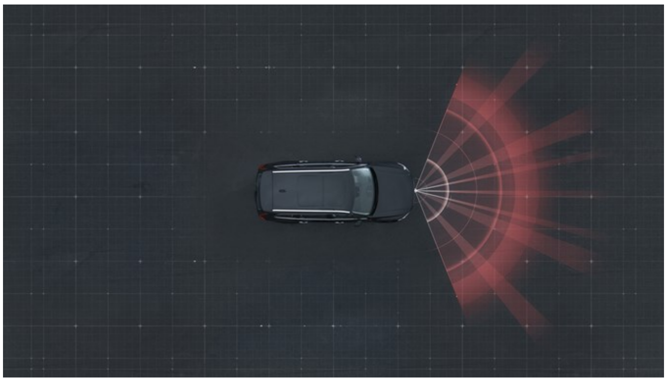

Figure 3.5: The laser system [27]

On an AD car there are also twelve ultrasonic sensors around the car used to identify objects close to the car. This supports AD in low speeds and helps to detect unexpected situations with for example pedestrians and other hazards on the road close to the car [27], Figure 3.6.

Figure 3.6: The ultra sonic system [27]

Multiple sensing systems are often required due to the complexity of the task [33], why the sensors are often used as a combination in sensor fusion giving an holistic 360°view of the surrounding [27] Figure 3.7.

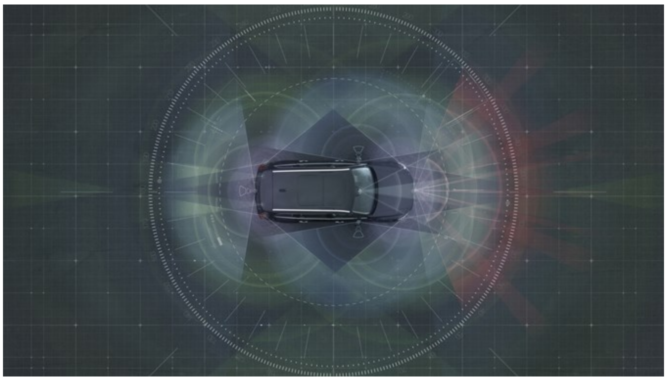

Figure 3.7: All systems working together [27]

3.3.4 AD intelligence

The intelligence of the car, to make decision and to process data from sensors, are pre-programmed in the car [51]. To be able to respond to all different kinds of traffic conditions, the car must be able to detect other cars or pedestrians and information signs in all types of weather conditions and for all types of road situations [33]. This is a prerequisite for the car to know how to act in a situation. Depending on the information given through the sensors, the car makes decision of how to handle each specific scenario, depending on the programmed rules and procedures [51].

There are about 70 electronic control units (ECU) in each vehicle, controlling one or more of the electrical systems and software functions [52]. The ECUs are communicating with each other through bus systems [52]. A bus system is a communication network and the most commonly used bus systems in vehicles are controller area network (CAN), media-oriented systems transports (MOST), FlexRay and local interconnect network (LIN) [52].

In a premium car today the driver interacts with about 270 features which are composed of about 2500 software functions [52]. An example of a user feature is the central locking and examples of software functions for this feature is locking, unlocking and the remote function [52]. To process all information from the sensors and features and to communicate the information within the system requires a high amount of data. When talking abut AD processors the term is gigabytes and not kilobytes as it is today. This data are processed by five high performance computers [3].

3.3.5 AD navigation

Autonomous cars navigates by using a combination of several systems such as radars, virtual maps, satellites and other sensors [15]. The navigation systems used today based on GPS does not always guarantee sufficient precision and can therefore not be used by itself for the navigation of an AD car [49].

AD cars will only be able to drive autonomously if having access to a high precision 3D map of the surrounding environment. To be able to drive safely the car also needs to know its position on the road down to an accuracy of centimeters [44].

Precise digital driving instructions are also needed for the car to be able to steer the car. In addition to this the car sensors will provide the information needed about the environment [44]. The 3D map is built by a camera, scanning the environment while driving the route. The image data is then processed and the map is built [44]. The real world 360°image created by the sensors on the AD car is placed above the 3D map, giving a view of the current situation in relation to the pre-scanned environment [27], see Figure 3.8.

This will provide the car with information about its position in relation to the surroundings. The car will also be connected to the traffic authorities' control centre by cloud service to ensure that the

Figure 3.8: The cloud based 3D digital map [27]

latest up-to-date traffic information is available [27]. These systems will work together to make the car able to navigate itself on the roads. The traffic authorities' control centre operators also have the ability inform the drivers in AD cars that autonomous drive mode should be turned off meaning that the drivers take over control [27].

3.3.6 AD safety

With the AD technology the car can perceive obstacles with its 360°view and with its manoeuvre generator it is able to identify collision-free routes to help avoid accidents. This is one of the steps Volvo Cars takes toward their goals of no fatal accidents by 2020 [27].

Volvo Cars decided in October 2015 that they will take full responsibility actions performed by their AD cars when they are in the autopilot mode [17].

The detection system must be robust and able to operate in different environments such as bad weather conditions and for different purposes (e.g., detection of other vehicles, pedestrians or reading signs [33]). When the car is driving in AD mode it will always be able to take itself to a safe stop. If the car tells the driver to take command and he or she for some reason is unable to do so the car will always be able to take itself to a safe stop. To ensure the safety in AD technology all AD cars are equipped with redundant systems such as double breaking systems and two electrical control systems [3]. The second system works as a back up if the main component stops working.

3.4 Autonomous Guided Vehicle

An automated guided vehicle (AGV) is a vehicle driving without human intervention. AGVs are commonly used for transporting goods, products and material within industries, for example, in manufacturing and logistic areas. They are often used with the purpose to optimise these material flows [63].

3.4.1 The development of AGV

AGVs have been used for about sixty years and during this time they have been used in almost all branches of industry and production areas [63]. After the second world war the dream of having self-driving robots to ease the heavy industrial work began to take place and the development of AGVs started [63]. In the 70's the trend of having AGVs had reached car manufacturers who developed even more technically advanced AGVs due to their specific needs [63]. When the industrial recession came in the late 80's, the AGVs were practically abandoned within car manufacturing because they were expensive and not as flexible in practice as in theory [63]. When the AGVs became less expensive, more flexible and more efficient during the mid 90's the automotive industry adopted the AGVs again. The development is still going on and today it is possible to transport practically all types of material and products anywhere within a factory or in an outdoor environment [63]. The modern application areas for AGVs are many and AGVs are used in several different types of industries such as logistics [63], [61], fruit farmers [8] [29] and production material handling.

3.4.2 AGV navigation

An AGV moves within a fixed coordinate system which represents the operating area, this is sometimes called the global coordinate system [63]. The AGV have an own local coordinate system and that coordinate system needs to be positioned in the global coordinate system [63]. The local coordinate system can then be moved in relation to the global using navigation procedures [63]. To be able to navigate, the AGV needs to find its position in the known environment [67]. There are several positioning and navigation systems used for AGVs, they range from sonar [54] and camera based [36] to navigation using magnet patterns [37] or tracks on the ground [36].

The simplest navigation method for an AGV is following a fixed physical guideline [63]. Examples of this is grooves in the ground, which the AGVs follows. Inductance and magnetic wires can also be used, where the AGV senses the electromagnetic field [63]. Both these methods are relatively simple but it requires floor installations which is costly and time consuming both to implement and change [63]. A similar method which not requires floor installations is a camera based system using coloured lines and optical sensors. One drawback here is that the line can be worn out or unintentionally covered [63]. Then the AGV cannot navigate. These navigation methods, consisting of a fixed path, are not very flexible since the AGV is limited to the specific area where the lines are placed.

To make the navigation more flexible it is possible to use a series of optical or magnetic fixed points on the floor [63]. If the points are set in a grid instead of having a line, the area becomes more flexible since it is possible to create different routes by using the grid points [63]. The magnets will still need floor installation but because of the increased flexibility it can handle changes more efficient.

Laser navigation is a flexible navigation method that does not require floor installations. A laser transmitter rotates and sends out laser beams which are reflected back by fixed foil parts positioned within the factory [63]. The angle between the AGV and reflector is calculated which is enough for the AGV to navigate [63]. The laser head needs to have a free 360°"sight" meaning that the laser head has to be placed as high so operators or equipment cannot obscure the reflectors. If there are equipment or other buildings covering a wall it is possible to put reflectors on these or in the ceiling [63]. Another option is to 3D scan the ceiling and use the map of the ceiling to navigate [67].

In a GPS system the vehicle can position itself by comparing distance to satellites [63]. A GPS needs to have a clear line of sight from the vehicle to the satellite which makes it most suitable outdoor. Indoor one can use an LPR (local positioning radar) which works as an "indoor GPS". Instead of having satellites, radio beacons are used in the area. The LPR having an accuracy of about 30cm, which is not as accurate as a GPS [63]. In 1996 AGVs were introduced in heavy cargo ports where the AGVs had a navigation system using millimeter wave radar sensors and several fixed beacons in the AGV area [20].

3.4.3 AGV safety

When discussing AGVs in relation to safety the AGV is defined as a machine. An AGV used in a Swedish factory needs to follow the SIS (Swedish Standard Institution) standard [34]. This standard is based om the machine guidelines [63] and is used for both industrial and driverless truck systems [34]. AGV suppliers integrate the safety guidelines already in the design phase and the vehicles must meet the basic health and safety requirements of the Machine Guidelines [63].

An AGV today have different kinds of safety equipment [63]. All AGV has one or several emergency stops that is visible and easily accessed by everyone working around the AGV [63] and shall be used in an emergency situation. When a safety stop is activated the AGV stops immediately [63].

Another safety precaution is that the brakes of the AGV are intrinsically safe, meaning that they do not need power to not brake [63]. If the system stops working the AGVs will therefore stop directly.

In an indoor factory AGVs often operates in the same area as the employees [63]. The people around the AGV has to be aware of its presence and therefore the vehicles often have some kind of warning signal, optical or acoustic [63]. This also includes turn signals when the AGV is changing direction. The employees are able to some extent foresee the AGVs behavior since it follows a specific route and because of the low speed (3-4km/h) [63]. The AGVs are, however, silent which makes them harder to detect [63].

3.5 Standards and directives

There are several ISO standards and other regulations regarding both machine safety within industry and the usage of vehicles. There are no standards or regulations directly related to how AD technology could be used within car manufacturing. The following summarizes the standards that are relevant for this study.

Swedish Work Environment Authority - Use of Work Equipment (AFS 600:4) This regulation deals with usage of work equipment. It covers machines, devices and tools used while working. The activities related to usage of the machine/devices/tools are also covered. Examples of activities are the start and stop, transportation and other general utilization of a machines/devices/tools. It also covers risks in the environment where a machine is operating.

The appendix contains additional requirements on special work equipment such as mobile work equipment (A 3.1) . This applies to both self-propelled and non-self-propelled mobile equipment. The standard defines requirements all mobile equipment should fulfil and also specific requirements on self-propelled machines.

Safety of industrial trucks – Driverless trucks and their systems (SS-EN 1525): This standard applies to all trucks except trucks guided by only mechanical means, such as rails and other guides, and trucks operating on environments where the surrounding persons are not aware of the hazards connected to driverless trucks. The standard states requirements to minimise hazards when implementing, operating and maintaining. The standard also includes minimum safety requirements for the preparations of the environment where the trucks should operate.

The definition of driverless truck in this standard is a powered vehicle that is designed to travel automatically without a driver responsible for the safety of the vehicle. In this case remote controlled vehicles are not considered to be driverless. The control system can be both a part of the truck or separate from it.

Machinery Directive (95/16/EC): This directive defines the basic health and safety requirement for machinery with the purpose to increase safety for working with the machinery on the European market. The social cost due to the high number of accidents caused when working with machinery can be reduces if considering safety in the design and manufacturing phase. This directive is therefore directed to manufacturers and distributors.

The machinery directive mainly comprises machinery but also interchangeable and safety components, lifting tool and chains. It does not include agricultural tractors, motor vehicles covered by the directive 70/156/EEC, two or three wheel vehicles, weapons, and means of transportation in air, on water or rails. The directive defines a machine to be a unit assembled from different component with at least one moving part. A machine shall be equipped with some kind of power train or be driven manually by manpower. The machinery directive is of interest since it includes AGVs.

Motor vehicle and trailers (70/156/EEC): This directive covers motor vehicle and their trailers. The definition of a vehicle is stated in the directive as a motor vehicle with a maximum speed over 25km/h intended for use on roads.

Road vehicles - Functional safety (ISO 26262): As the name of the standard says, this is adapted for vehicle intended to drive on road. It applies to safety system of series production passengers cars.

The standard highlight that vehicles tends to include more complex technology, software and mechanics. This leads to an increased risk for hardware and systematic failures. This is considered within the standard.

The way to self-driving cars - for testing [55]: The Swedish government have started an investigation of allowing self-driving cars to be tested on roads. It is suggested that a new law shall regulate this kind of tests. An analysis have been made to identify which new regulations that must be made to introduce this new technology. Permission to execute those tests requires applying for permission and fulfill requirements. When the vehicle is in self-driving mode shall all criminal liability borne by who applied for the permission. Another conclusion that the investigation assume is that the laws for camera surveillance must be adjusted. The new changes in laws adopted enter into force in 1st of May 2017.

4 Empirical Study

In this chapter the case study at Volvo Cars is presented together with the findings. Findings within the three focus areas AD, AGV and EOL are first described separately followed by the findings from the case study. Finally, the result of empirical study is presented in a table of issues identified based on the analysis of collected data. The result from the issue prioritisation work shop indicating which issues are most important for Volvo Cars to start work with is also presented. The data in the empirical study is collected at Volvo Cars. The nomenclature presented in Table 4.1 are used to define where the information comes from. This do not refer to a person but a departments within Volvo Cars to retain anonymity.

Table 4.1: Nomeclatur for the depatments

Reference	Department:
D1	Research & Development
D2	Logistics
D3	Manufacturing
D4	Production
D5	Safety
D6	Active Safety

4.1 Volvo Cars

Volvo Cars is a car manufacturing company in the premium car segment [16]. Volvo Cars has grown the last couple of years both as a company and on the market and in 2015 they sold over 500 000 cars and had about 1-2% of market shares [16]. Volvo Cars have several different car models but each car is individually configured and customized meaning that most of the cars are unique [16]. In the all new XC90 a new platform called SPA was introduced. The SPA platform together with the CMA platform will be the only architectures that Volvo Cars will use in the future. The SPA platform is adapted for AD and is one of several indications that Volvo Cars is aiming for a leading position within AD technology. The brand Volvo is a global brand and the cars are manufactured in Sweden, Belgium and China [16].

In general, Volvo Cars plants are divided into three shops: A, B and C. The A-shop is the Body shop, the B-shop is the Paint shop and the C-shop is the Assembly shop. In the Assembly shop, the car is transported first on pallets and skids on the line. The last part of the Assembly shop is the EOL area and here the car is fully assembled and completed.

Volvo Cars believes that developing the AD technology and its potential benefits for the customers is key for being competitive in the future and aims therefore to be leading within this area. For example, Volvo Cars sees that AD technology can improve safety which is in line with their vision that no person should be killed or seriously injured in a Volvo Car after 2020 [31]. Thus, Volvo Cars is an interesting company to perform a case study related to AD technology.

4.2 Case description

The empirical research consists of a case study at Volvo Cars in Torslanda. In the study the focus were to identify and investigate challenges by using AT within the EOL area. As mentioned earlier, in Section 1.1.3 AT - Autonomous Transports on page 2, AT is defined to be a combination of the two technologies AD and AGV. In this case study, the three main focus areas AD, AGV and EOL was therefor investigated, see Figure 4.1. The case study only involved people working at Volvo Cars in Torslanda and was conducted during spring in 2016.

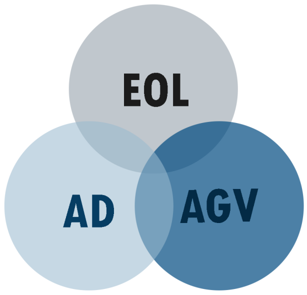

Figure 4.1: The focus areas for the case study

4.3 End Of Line

The information presented here have mainly been collected during observation within the manufacturing area. There has also been two walk through the space observations together with the industrial supervisor and one with the production expert. During the observations conversations and questions was held with the supervisor, the production expert and people working within the processes of interest.

EOL is the last section of the Assembly shop and consist of the two main areas, the final line and the after line and the stations as shown in Figure 4.2. When the car arrives to the final line it is almost fully assembled, the software is downloaded to the car and required tests of the complete car is performed. The software and most of the functions are tested. On the final line the car is still transported on a line and operators are working at several stations along the line. The final line ends where the car is first started and transported from the line by an operator driving the car.

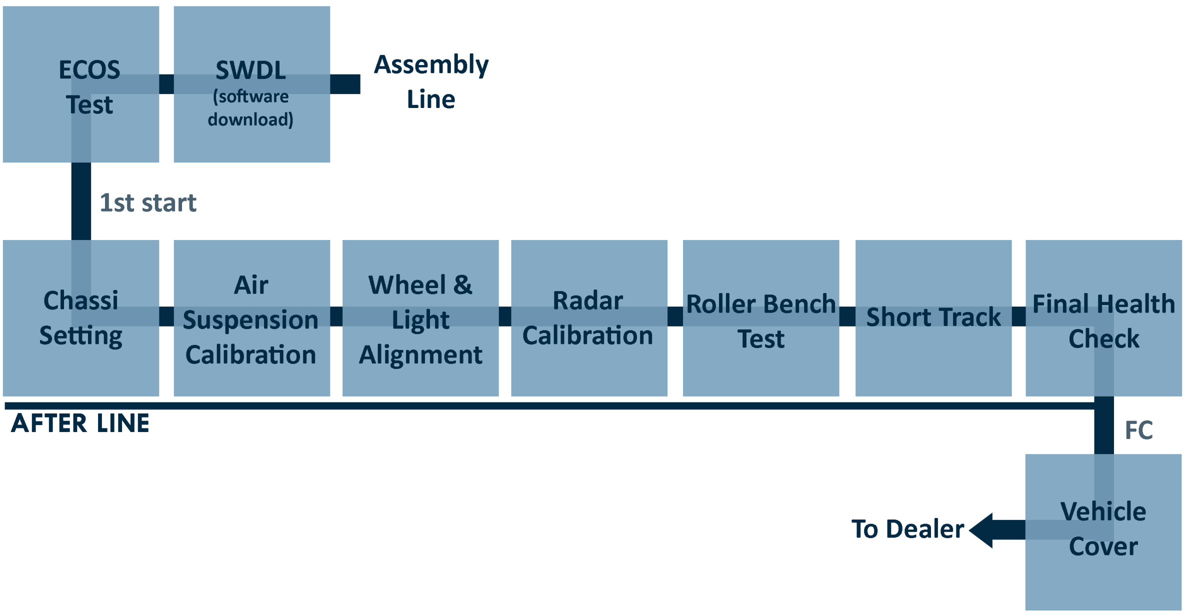

Figure 4.2: Some of the EOL Processes

The after line consist of several transportation distances between stations where, for example, the cars are calibrated and tested to secure the quality. The after line area is the focus in this study and it includes the stations Chassis setting, Air suspension calibration, Wheel and light adjustment, Radar calibration, Roller bench test and the Short track. The internal logistics of cars in the after line area is operated by the people working in the area who drive the cars between the stations. For example, the operators working on the Radar calibration drives the car either from the prior station, the Wheel and light adjustment or/and to the next station Roller bench test. All stations are further described in section 4.3.1 Station description, page 30.

In the EOL area there are both humans and cars operating. There is a lot of empty spaces and and the environment is relatively open. There are restricted areas where it is only allowed to walk and areas where the cars are driven. In the areas where the cars are driven the operators are however allowed to walk as well. This means that cars and operators are working in the same areas and the operators work close to moving cars. In the factory there cars are limited to a speed of 30km/h.

After the Short track the car is put on a two smaller lines, which the operators drives the car to and from, and is then finally tested in the so called Final health check. If there are no errors the car becomes factory complete (FC). A vehicle cover to protect the car from damage during transportation to retailers is put on some of the cars and the car is driven by an operator from the factory to the yard for transportation to retailers.

4.3.1 Station description

In this section the stations in the EOL area are described in further detail. As stated above, the EOL consists of two parts the final line and the after line. The after line is the focus in this study, however all stations is described to get a holistic view.

Software Download and electrical test: This is one of the last stations in the final assembly line. Here the battery is connected, the car is configured and it ”comes to life”, meaning that the electrical systems are started.

First the car is manually scanned and an external diagnostic tester, called IFLEX, is connected by wire to the car and is then placed on the steering wheel in the car. The IFLEX is a device that contains data for configuring and testing the car. The car is identified through manual scanning, which in turn provides the configuration of the car, e.g., what software should be downloaded and what tests should be run. The IFLEX downloads the software which takes a couple of minutes and runs electronically tests single out for the specific car. For example, the windows and tailgate is opened and closed and the headlight is switched on and off, this is a few visible examples of what is tested during the electrical tests, also called ECOS.

First start: At the end of the assembly line the car is started for the first time. The car is driven by an operator a few meters and the operator makes a small break test, then the car is driven of the final line, makes a U-turn and goes to the next transportation line. At the end of this line, the car is driven by an operator to the Chassis setting station.

Chassis setting: The Chassis setting consists of a few meters of cobblestone. The length of the cobblestone area is around ten meters and this station ensures that the chassis is set. The Chassis setting must be done before some of the following tests since it affects the height of the car and these tests are dependent on an accurate chassis height.

Air Suspension Calibration: During the manufacturing of the car the air suspension reservoir is filled with air to a maximum level. In the Air suspension calibration station the amount of air is adjusted.

The position of the car is set longitudinally by having the front wheels in lowered floor slots and laterally by mechanical shovers pushing the wheels form the inside. When the car is in the right position the exact height is measured by cameras. An IFLEX is manually connected to the car which in turn communicates with the car by wire in order to regulate the pressure in the air suspension system and adjust the car to the specified height.

Wheel and Light Adjustment: The car is driven into the wheel alignment station by an operator and is placed into the correct position with support from rolls in the floor. The station is divided into two sub stations. One in front of the car where the headlights are adjusted and one underneath the car where the wheel angles are adjusted.

At the station in front of the car the cap is opened and a camera is positioned in front of the headlights. The camera measures the light angle which is displayed on a screen visible to the operator. The light angle is manually adjusted until the angle is aligned with the reference shown on the screen.

There is a pit in the floor giving the operator access to the under body of the car for adjusting the wheel angles. The wheel angels are measured automatically and the operator gets instruction of how to adjust the wheels on a screen. When all four wheels are adjusted, the test result are stored and displayed and the car is driven from the station by an operator.

Radar Calibration: In this station the radars and cameras in the car are adjusted and calibrated. The car is driven into the station by an operator. The operator connects an IFLEX. The car is set longitudinally by having the front wheels in slots in the floor and laterally by mechanical shovers pushing the wheels form the inside. When the car is in its correct position the exact height is measured by cameras from the side.

The radar is vertically aligned in the car using the measured height and a camera target, which is a board with black and white patterns, that is lowered a few meters in front of the car. Based on this data the car calculates the angle deviation. The operator enters the car front seat and uses a tool to adjust the radar vertically. Finally the radar is horizontally calibrated, using a board with 3D prisms. The side and back cameras a.k.a. 360°cameras are calibrated, using white lines on the floor. When the test is completed, the results are stored and a message is displayed.

Roller Bench Test: The Roller bench test is a dynamic test station where primarily engine emissions and driveability is tested. The car is driven by an operator, through a narrow opening, into a test booth equipped with rollers on which the car can be driven. The operator scans and connects an IFLEX to the car. When the car is positioned in the rollers and the operator is seated in the front seat of the car the tests starts.

During the tests, the operator drives the car and gets instructions of what to do through a screen in front of the car. For example, the operator is instructed to accelerate, brake and test the windscreen wiper and the AC system. The duration of the Roller bench test is about 4-5 minutes. While the operator follows the instructions other tests are done automatically, for example the emission test. When the test is completed the front door of the test booth is opened and the car is driven out from the booth.

Short Track: The cars driveability is also tested on an indoor Short track. The track consist of different road conditions and humps. The purpose is to make the operator feel deviations and hear noises that indicates some kind of error. This test is done in 25km/h to make sure that the ride discloses the possible errors.

Final Health Check: At the Final health check the car is electrically tested for the last time. An operator connects an IFLEX to the car and if there are no errors the car becomes FC. In this station the transportation is done automatically on a line and no operator needs to transport the car by driving it.

Factory Complete: At this point the car is completed and ready to be delivered from the factory to the end customer. The car have passed all tests and have no errors.

Vehicle Cover: For some cars a protection cape is mounted to maintain the condition of the car's surface during the transportation to retailers. The protection cape is a white plastic cover that is put on the car before it exits the factory. It is designed to enable the driver to enter and exit the car and also have enough sight through the windscreen to drive in low speeds. However the cover limits some functions of the car, for example is the rear parking sensors in the back of the car constantly activated because of the cape.

Transport To Dealer: When the car is driven through the factory door and placed on the yard, the logistics department takes over responsibility of the car. This is the end point of the EOL area and the car is ready to be delivered to customer.

4.4 Autonomous Drive

Volvo Cars will in the near future produce level 3 AD cars, see Section 3.3.2 Definition of Level of automation on page 20. To develop a level 3 AD car is a part of the Drive Me project where Volvo Cars plays a large role [D1]. In these cars the driver will starts driving manually and the display in the car will give a signal when it is possible to drive autonomously. The car will then take full control over the car if it is accepted by the driver [D1]. The driver can easily give away the control of the driving to the car or take it back through a simple command [D1]. In a first stage the AD technology will only be available on specific roads in Gothenburg that are wihin the scope of the Drive Me project. When the car drives autonomously, the driver has time to do other things such as relaxing, e-mailing or watching a movie [D1].

The car can at any time tell the driver to take back control of the car, for example, when the car is reaching a point that is not within the Drive Me route it will inform the driver to take over the control again [D1]. If the driver for some reason are unable to take back the control, the AD car will always be able to stop in a safe way. For these AD cars, Volvo Cars will takes the full responsibility of the driving when the car is driving autonomously [17]. The AD technology that will be used on public roads in the Drive Me project will be adapted for use in high speed and the sensors are designed and optimized for this. Radars, cameras, lasers and ultrasonic sensors are interacting with each other and a driver must always be in the car.

There are however functions with the purpose of driving in slow speeds without a driver, for example the FAP project. This is also a part of the Drive Me project and in this function mostly the camera and ultrasonic sensors work together to get a clear picture of the surrounding. The FAP function have a high take away compared to AD meaning that more cars will be equipped with this kind of sensors [D6]. Some parts of the FAP function are found already today in the All New XC90. Here the steering is automatic but the driver must accelerate and break, so a driver is still required in that function. With the FAP function the car will be able to park completely autonomously. The driver will exit the car and by using a smart phone be able to tell the car to go and park itself.

In AD technology, one of the main challenges is driving in a complex and changeable environment as the public roads are, e.g., the traffic, the weather and the light conditions varies [D1]. Furthermore, there are objects and obstacles in the surrounding of the road or other activities going on around that the car needs to identify and evaluate. The car must be able to handle all types of traffic situations and detect cars, pedestrians and lane marks. This contributed to the complexity of the AD technology.

4.4.1 AD intelligence

The behavior of AD cars is controlled by computers, a.k.a. electrical control units (ECU), in the car controlling how the car accelerates, steer and brakes. It is crucial that the behavior of this type technologies is dependable, i.e. safe, reliable and available [D1].

Today Volvo Cars process a lot of information and communicate both external and internal with other units. AD includes several new features and when these becomes more advanced a larger amount of data needs to be processed and faster communication is required. This implies increased amount of software, an efficient communication networks in the cars and continuously improvements of the existing technologies.

The schedule over the communication networks and ECUs in the car is specified in a so called topology chart. AD includes several new parts, which have an influence on the topology. The topology is divided into different network domains. The domains consist of ECU's communicating with each other on different networks in order to control allocated functions. For each domain there is a domain master ECU connected to all other ECU's in the domain. Examples of domains are vehicle dynamics (controlling for example the engine, steering and breaks), safety and body (controlling for example climate and comfort).

4.4.2 AD navigation

When the AD mode is on, the car will navigate and position itself on the road. The AD car is then navigating by using a virtual map in combination with a GPS. To only use the GPS is not accurate and robust enough [D1]. An AD car is navigating by scanning the environment using its own radars, cameras and laser sensors [D1]. The car's interpretation of the reality is continuously compared to a high definition 3D map that shows the surroundings from a camera and radar perspective [D1]. This means that all roads used during AD must be pre-scanned into a map that is available for the car. The car uses the reference points on the map and compares it with the data from the sensors for determining its position. The sensors also monitors the lines of the roads for determining the lateral position of the car [D1]. The precision of an AD car is around +- 10 cm.

To enable a car to drive autonomously in a new environment, a major part of the AD function development involves preparation work but in theory it would be possible to drive anywhere, even indoor, if the environment is pre-scanned. There are however situations that limits the possibilities to navigate, e.g., bad weathers with certain light condition, snow and rain [D1] or an environment that is constantly changing.

4.4.3 AD safety

For the AD cars, one main challenge is the trade-of between safety and availability. When an AD car perceives too high uncertainty of a situation, it will make the AD function unavailable by requiring the driver to take over the control stopping itself safely. This result in a safe situation but no availability to the AD system. The opposite situation would be to force the system to always be available, but this would result in increased risk, jeopardizing the demands on safety. A major part of the development of the future AD technology at Volvo Cars is the balance between safety and availability [D1].

Currently, AD is mainly developed to be used on high speed roads. This is an environment where there are usually no pedestrians and consequently the AD cars have cameras and radars that have not been primarily developed to detect obstacles moving in the area close to the car. The sensors need to detect the whole obstacle in order to identify pedestrians, cars or cyclists and the identification is required for the system to act properly. For example, if a person is positioned too close to the car before it has been detected, the AD car cannot see the whole person, meaning that it will not identify the obstacle as a human and therefore not know how to act. The radar also have a blind-zone which makes it unable to detect obstacles positioned within the distance of some decimeters from the car.

These factors can be a problem in low speeds where obstacles are positioned close to the car, for example in a parking lot.

In another type of AD, the FAP function, the car is therefor using other types of sensors. These sensors are developed for usage in low speeds and with pedestrians and other objects in the surrounding area. The sensors used for this are ultrasonic sensors [D6].

The AD car will be able to do self diagnostics so that the car always knows that all systems are functioning while driving. For this, the AD system has an integrated safety function monitoring and evaluating critical parameters in order to secure that the system works properly. If a system is not working as it should, the car will tell the driver to take over the control or stop itself safely. In addition, the car is provided with redundant systems and components such as double computers, double sensing systems and double brake systems in order to achieve required safety demands on the AD system [D1].

4.5 Automated Guided Vehicle

AGVs are used at several locations within Volvo Cars's factories. One type of AGVs are used in the Body shop for material handling of large metal components such as the roof, metal sheets and side parts of the car [D5]. This AGVs dimensions are 1,6 x 4,5 m and it can transport gods of maximum 2000 kg. One reason for using AGVs in the Body shop is to make the factory fork lift free [D5]. Fork lifts is a relative insecure way of handling material in an environment that involves humans and having AGVs instead makes the environment more safe. Another location where AGVs have been used for a long time is the Volvo Cars's warehouse in Torslanda. The AGVs was mainly used to transport pallets and where a lot smaller than the AGVs used in the Body shop. The AGVs used in the warehouse were however recently replaced by conveyors that, according to the personnel at the warehouse, is a more efficient solution.

4.5.1 AGV navigation

The positioning system of the AGVs used in the Body shop is a laser navigation system combining laser measurement and odometry. The active laser head is placed on the top of the AGV and passive reflectors are placed on the walls in the factory, in the same height as the laser head. The laser head must be able to see the reflectors to know its position, therefore must the reflectors not be obscured by other objects. This problem is solved by placing the laser head and reflectors 3,6 m above the ground. By measuring the angle of the reflected light beam the AGV is capable of determine its position in the factory. The AGV's on board controller then control the movement of the AGV through its motors. There are several reflectors placed in the factory but the AGV only needs to see a few reflectors to position itself anywhere in the factory [D5]. The controller has also information about the route layout of the factory. If the AGV's position deviates from the planned path more than the maximum allowed distance, the AGV directly stops and sends an alarm to an operator [D5].

All AGVs are continuously communicating with a central control system using WLAN. This system keeps track of the AGVs position and status [D5] and handles the scheduling transport operations and the traffic control (to prevent collision between AGVs in operation).

The type of AGV recently used in the warehouse were navigating through conductive wires mounted in the floor and communicated through so called communication points. The communication went through so called communication points. Four wires were placed in parallel and each wire represented a specific command which instructed the AGV what to do [2]. These AGVs were unable to communicate between the communication points [2] implying that it was of extra importance to ensure that the right information was received by the AGV before it left the communication point [2]. When an AGV is navigating by wires and deviates from the planned path, it loses connection with the wire and stops automatically. This can be seen as a safety system for this type of driverless transports and can prevent the AGV from moving without control [2]. One negative aspect with this navigation system is the inflexibility and the required reconstruction of the floor when changing the AGV path [D5].

The required accuracy for the navigation and positioning system varies depending on the use of the AGVs [2]. In the case loading or unloading material on a conveyor line the accuracy is more important than when the AGV is moving between two stations.

4.5.2 AGV safety

Volvo Cars follows the European Machinery Legislation when using AGVs since they are, per definition, machines. Information about the European Machinery Legislation can be found in section 3.5 Standards and directives, page 26. Volvo Cars also have speed limitations for their AGVs. When an AGV is travelling in 15 m/min it is a safe speed while a speed over 30m/min is defined as speed where safety jeopardized [D5]. At Volvo Cars the AGV does therefor not move faster than 30 m/min. It would however be possible for an AGV to move in higher speeds but it would require safety equipment, for example, enclosing of the area where the AGV is traveling to make sure the risk for humans to get hit by an AGV is eliminated [D5].

One of the most challenging safety aspects when implementing AGVs is to make the system compatible with other machines and systems [D5]. AGVs and fork lifts, for example, are hard to use together [D5]. Sometimes the AGV does not detect the forks on a fork lift since the radars only scans in one plane [D5]. Pedestrians and human operators are also an important aspect when implementing the AGV system [D5]. As always when implementing driverless transportation systems, it is not wanted to have people in the surrounding area [2]. Another aspect when having people in the same area is that the AGVs may be stopped because people are standing too close, the people can then make the system unavailable which is critical when using AGVs together with a production system that is sensitive for disturbances [D5].

The AGVs in the Body shop are equipped with several safety radar and sensor systems [D5]. In front of the AGV there is a radar scanning a horizontal plane field about 0.2m above the ground. The field is divided into three sections. If the radar detects an object in the outer part of the safety zone, the Warning field, it will reduce speed. When the object is getting closer and is detected in the Stop field the AGV will stop but auto start when the object is removed from the stop field. If an object is detected close to the AGV in the Safety field the AGV will do an emergency stop. The length of the scanned field increases with respect to the speed of the AGV (1,4-2,0 m/s [D5]) and these safety precautions are category three according to ISO 13849. To further prevent injuries like for example crushing injuries the distance between fixed and moving parts must be minimum 50cm in a Volvo Cars factory. This applies in areas where humans are present.

Both the modern and old fashioned AGVs use bumpers to detect if it hits something from the side. These are used to protect operators from injuries. This is a mechanical sensor along the side if the AGV making the AGV stop when hitting something from the side. The AGVs from the warehouse only had bumpers in the front which triggered safety stop [2]. This means that there were a possible collision risk between the side of the AGV and for example a loading station. On modern AGVs there are no bumpers in the front since that is covered by the safety radar but there are bumpers on the sides to secure the risk of side collisions.

To increase the safety level further on the AGVs in the Volvo Cars Body shop there are two radar sensors on each side of the AGV scanning vertical planes along the side of the AGV, this together with the horizontal plane makes scanned a U formation which is illustrated in Figure 4.3. The purpose of these vertical radars is to cover the area that the front radar cant see, the area higher or lower than the scanned plane about 0,2 m from the ground. The side radars and front radar will together detect any object in front of the AGV that is within the U form the radars detect.

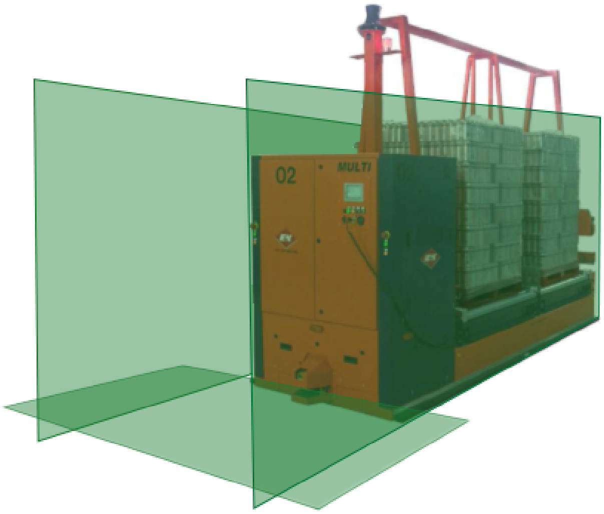

Figure 4.3: AGV with visual radar planes

4.6 Interview findings

This section describes the findings from the interviews in the case study. The five semi structured interviews held with people from the five departments (described in section 2.3.7 Empirical study procedure, page 10). The sub sections in this chapter are based on the structure from the interview guide, see Appendix A on page 57.

4.6.1 Possibilities with AT

Overall, the interviewees thought that AT has the potential to be used everywhere where a car needs to be moved, as long as the AT is completely safe [D1, D2, D4, D6]. There are obvious benefits with AT in the factory environment. As one of the interviewees stated “The way the cars are transported in the factory today is not very effective - an operator jumps into the to drive it 10m forward and then jumps out of it” [D6]. The interviewees also mentioned that AT increase the operator safety [D2, D5] and cars can be tested more efficient by replacing operator driving the cars with AT technology [D3, D4].

AT could also be optimising processes in other areas, for example within yard logistics where personnel transport the cars on the yard before shipment. This was a common opinion among the interviewees [D2, D3, D5]. As one of the interviewees put it ”Just imagine that we need to move 100 cars from one side to the yard to the other. Several drivers are required o do this, and then they would have to walk back” [D5]. Another benefit mentioned was that safety would most likely increase when the amount of personnel decreased in the area where the cars are transported [D2]. Furthermore, the space needed for parking the cars could be lessened since personnel do not have to enter and get out of the cars and AT would probably follow instruction more accurate than humans [D2, D5].

4.6.2 Limitations with AT

Safety is generally seen as a challenge by the interviews but there are different aspects of if. When using a machine in a factory it needs to have a specific safety classification - ”At Volvo Cars all safety equipment have classification three or higher” [D5]. Rules and standard of how it is allowed to use machines could also be a problem if introducing AT in car manufacturing [D2, D5]. Another safety aspect mentioned is the fact that the systems in the car would only be electronically tested before used. One of the interviews compares AT to an AGV - "An AGV is always test run several times before it is released in a factory environment, that will not be possible with AT. The car itself have to assure that it is safe without any tests run" [D5].

In the factory it is important that AT have a high availability and safety is according to one of the interviewees a trade of to availability [D1]. "To turn of the car would make it completely safe but the functions would not be available and if all functions are required to be available all the time more risks are taken" [D1]. A similar trade of is also identified by another interviewee meaning that if there are too many people in the manufacturing area and AT would stop for all of them to assure a safe environment it would eventually affect the availability [D5]. The interviewees however sees the possibility of controlling the environment making both safety alone and this trade of a bit easier [D1, D2, D5].

The environmental differences between AD on common roads and AT in the factory environment is pointed out by the interviewees [D1, D6]. The reflection from the interviewees was that utilization of AD technology is not possible to just tune and use in a factory environment [D1, D6]. To develop this technology in the future is theoretically possible but as one interviewee puts it "It is a huge work" [D1]. To have AT in mind when developing a new car and to work in cross functional teams is stated as an important factor when handling this kind of differences [D3].

Several interviewees agree that AT must also be profitable to be sustainable for Volvo Cars [D1, D6]. In car manufacturing the resources and in particular, operator time constitutes a major cost in manufacturing which makes AT interesting [D3]. Many of the interviewees however seem to think that this depends a lot on what systems in the car is used for AT, for example, if the existing systems can be adapted or if additional functions and equipment is needed [D1, D2, D4, D5, D6]. One of the interviewees also discussed the impact of the fast technology development - "Further on there may be technologies more suitable for AT than what we have today, for example when using AD in the urban environments" [D6]. The same interviewee also mention the take away of different functions of the car which is seen as a great factor deciding how the mix of AT non-AT will be [D6].

4.6.3 Where to use AT

Through the interviews it has become clear in what places AT may be applicable within the car manufacturing, this however depends on several parameters. The parameters mentioned are the environment, the type of tests performed and the order of the processes.

The interviewees are not completely in line when it comes to the complexity of the environment in the factory. If comparing to the environment where AD is aimed to be used the the factory environment is seen as complex by some interviewees [D1, D6] - "The AD function that are developed for the near future will be restricted to selected roads that do not have a lot of pedestrians, cyclists and traffic lights to make the initiation of AD less complex [D6]". One interviewee mentioned that it is challenging to mix systems such as forklifts, humans and AT [D5]. Other interviewees sees the factory environment as less complex due to less actors and being able to control the environment [D2, D5]. Several interviewees are referring to restricted areas and AT zones for the use of AT since it can increase both the safety and availability [D1, D2, D3, D5, D6].

Some interviewees stressed the potential of using AT between the line and test stations since the cars only need to gas, brake and steer to transport itself [D1, D2, D4]. Some thinks that the Short track and Roller bench test has a higher potential for using AT due to the restricted area [D2, D3, D5] while some do not agree [D4]. One interviewee sees problems with having AT in some of the tests - "In the Short track and in the Roller bench test, the operators are listening for sound and trying to feel indicators for errors" [D4]. The interviewee means that these human functions may have to pe replaces in the process by technology.

Depending on how AT is designed, there have to be different levels of control before it is used [D4] for example, the radar must be calibrated before it is used [D5]. One interviewee have identified a clear trend that the calibration quality of components coming from supplier are increasing [D4]. "If the components are accurate enough it may be possible to use them for AT directly and only tune it in house" [D5].

4.6.4 Characteristics needed for AT

There are several characteristics mentioned by the interviewees that will be required if using AT.

Many interviewees points at the importance of AT being aware of its surrounding [D2, D3, D4] and some also stated the importance of the surrounding being aware of AT [D2]. The car needs to know where it is [D5] and where to go [D3, D5]- "for example when going into a Roller bench test it needs to know which one to go to" [D3]. An overall opinion is that the navigation is a challenge. "The positioning of the car have to be accurate enough to apply to the rules in the factory" [D5] One of the interviewees mentions the importance of having a flexible system - "systems that are implemented in the floor tends to bring large costs if changes are needed" [D4].

An additional characteristic mentioned by the interviewees is the low speed. "The high speed which AD is developed for have a large impact on how the sensor setup on an AD car is designed" [D6]. Some sensors on an AD car are however mentioned to be better adapted to low speeds that others - "the ultrasonic sensors that brings the same characteristics that is used in the FAP and that may be suitable for AT" [D6]. The same interviewee states that these sensors would be able to function in a short range and low speed and can be used together with the camera.

One of the interviewees mentions that AT may need to have some kind of emergency stop [D5]. "If it is not possible to put a stop button on the car it may be possible to section the factory area and buttons in the surrounding to be able to turn everything within the area off" [D5]. It may also be required to have a safe communication between the car and the surrounding environment all the time [D5].

A general comment among the interviewees is that AT needs to be able to detect if an error occurs on itself [D1, D2, D3, D4]. - "It must be assured that the car is in good enough condition, and since the operator is taken away human ability to notice if anything feels och seems wrong in the car it must be able to do this by itself" [D4].

In the test stations the operator performs tasks manually - "if taking away the operator abilities such as senses, actions and knowledge are taken away as well" [D1]. At some test stations it is a bit unclear what must be tested. Some interviewees mean that specific tests must be performed while other states that the tests are done as an effect of having an operator in the car for several minutes. Overall the interviewees are however positive and believes that the manual tests can be replaced by technology even if it is a challenge - "feeling in the wheel and pedals is hard to replace but not impossible" [D4]. Some interviewees states that AT may have to have an automatic gearbox [D3] this applies to both transportation between stations and reversing the car [D5, D6]. The information flow to and from the car is also done manually - "today a car is also manually scanned by operators several times in the EOL" [D3].

4.7 Issue presentation

By using the methods presented in section 2.3 Empirical study, page 6 the case study resulted in seven identified issues. The issues represents the different categories of challenges of using AT in car manufacturing based on the specific case study at Volvo Cars. The issues are presented with a short description in Table 4.2 and are further discussed in section 5.3.1 The seven issues, page 43.

Table 4.2: Table of Issues

Issue	Short Description
Autonomous Guidance & Control	The car must be able to drive autonomously in the factory without human interaction. The car will also need a continuous control while driving autonomously.
Process Pre-requisites	There are different prerequisites that the process needs to adapt to such as test precedence, substitutes for the operators and the various availability of technology.
Dependability	AT needs to be capable of performing a required function under given conditions at a given point in time. This includes both requirements on the reliability of the product and the availability of the process.
Human-AT interaction	The operators and the AT technology will be two different systems that will have to interact with each other. This must be done in a safe and efficient way.
Regulations	It is unclear what AT can be defined as and therefore also which regulations should be applied. Today there are no obvious standards or regulations consistent with AT.
Finances	To develop a system that supports AT in car manufacturing will require an investment. Using AT must be profitable to get the investment.
AT-AD gap	AD technology is developed for another purpose than AT and must therefore be adjusted to be able to use as AT.

Table 4.3 gives an overview of how each issue is supported by the qualitative data collected in this study. The symbol X means that the departments representative discussed the issue during the interview. A bold **X** symbolize that the interviewee expressed that specific issue as a main issue. If the column is empty, the subject was not mentioned during the interview. The interviewees are anonymous but the departments are shown with the same nomenclature as presented in Table 4.1. Many of the issues was discussed by several interviewees. For example, the issues Autonomous Guidance and control and Human-AT interaction are supported by all participants.

Table 4.3: Discussed during interviews

Issues	D1	D2	D3	D4	D5
Autonomous Guidence and control	x	**X**	x	**X**	**X**
Process prerequusites	x	x	**X**	**X**	**X**
Dependability	**X**		**X**	x	x
Human - AT interaction	x	**X**	**X**	x	x
Regulations	**X**	x	x	x	
Finances	**X**	x	x		
AT-AD Gap	x	x		x	**X**

4.8 Prioritisation results

The prioritisation were conducted during the workshop where the participants distributed 100 points between the seven issues. They should state which issues that are most important to focus on first and distributed the points freely. A high points represented a high importance. Low points represented low importance. The diagram presented in the Figure 4.4 consist of a bar graph, showing the total points for each issue, and a line chart indicating the disagreement among the participants.

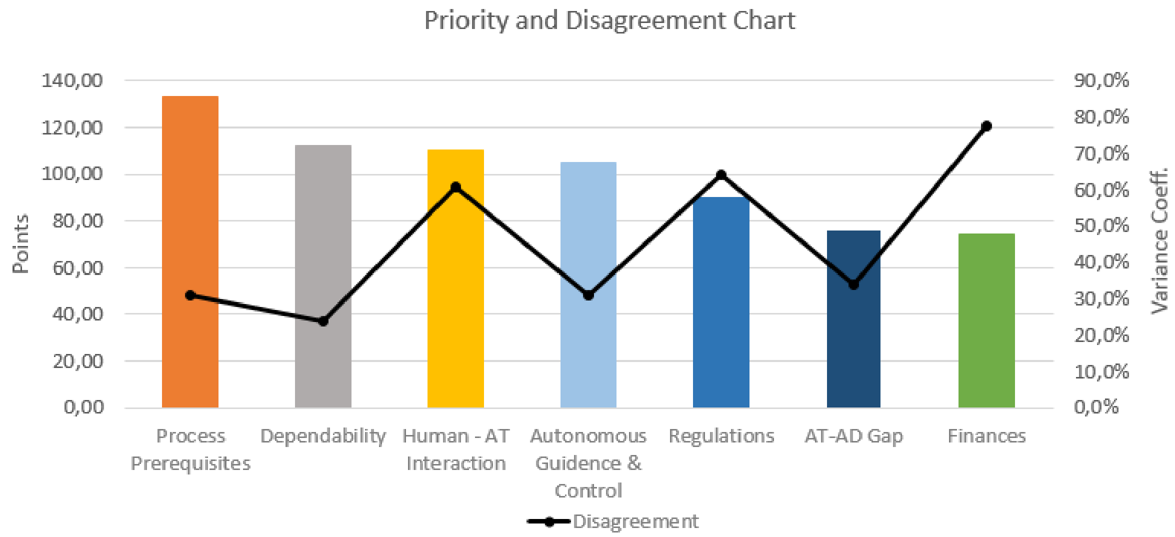

Figure 4.4: Total points of each issue and disagreement of prioritisation

In the bar graph, the issues are sorted from left to right with respect to their assigned points and shows the total points for each issue. The number of points is however not the main outcome here, the main outcome of this is that it gives an indication about the different issues importance in relation to each other. The issues with the highest points are Process Prerequisites, Dependability and Human – AT Interaction while the issues Finances and AT-AD Gap have the lowest points. The total points are relatively even between all the issues which is seen as indicator that all issues are important.

The disagreement chart shows that the variation between the distributed points for each issue varies. To calculate the disagreement, the variation coefficient was used. The coefficient was calculated as the standard deviation divided by the average of the priorities for the issues [56]. A large disagreement for an issue means a large variation in the points given by the participants [56].

The highest disagreements were found at the issues Finances, Regulations and Human – AT Interaction where the variance coefficient was between 60-78% . The issues with the lowest disagreement were Dependability, Autonomous Guidance & Control, Process Prerequisites and the AT-AD Gap where the variance coefficient was between 23-34%. It is important to be aware of the disagreement of the result when analysing the data since an issue with a low variance coefficient can be considered more reliable than a result with a high variance coefficient.

The result from the empirical study is the seven issues, identified by the use of the Affinity diagram, based on qualitative data from interviews and observations. The result from the prioritisation work shop states which issues that are most important for Volvo Cars to start working with. This order is:

1. Process Prerequisites
2. Dependability
3. Human - AT Interaction
4. Autonomous Guidence and Control
5. Regulations
6. AT - AD Gap
7. Finances

Which means that the most important issues for Volvo Cars to start work with are Process prerequisites, Dependability and Human - AT interaction. It is also shown that all issues are important for Volvo Cars to solve in order to use AT in the EOL area.

5 Discussion

In this chapter the different methods and how they have been adapted to fit this study are discussed. The three focus areas and the issue identified are analyzed and discussed in relation to the theoretical framework. Finally, recommendation for future work and a validity evaluation of the thesis are presented.

5.1 Choice of methodology

The methodology used for the empirical research is a combination of several independent methods. When combining the methods, some were tailored to make them applicable to this specific case study. To adjust or extend a method may affect the outcome, this has been taken into account. The following discusses the methods used in the different steps of the case study.

5.1.1 Interviews

It was important that all interviewees were guaranteed anonymity and that sensitive information would neither be published nor possible to trace to individuals since it could hinder them to express their opinions. One of the main goals with the interviews was to cover the whole spectra of possible issues. Therefore, the selection of interviewees was important in order to capture sufficient knowledge and experience covering the area of interest, i.e. difference among the participants would yield different issues. A semi structured interview guide with open questions where used to not limiting the scope too much, but rather discuss the themes that was brought up by the interviewees. This enriched the discussion around the questions.

The interviewees had not discussed AT before the interviews. This meant that the interviewees did not have much time to reflect about AT before answering the questions. An advantage of this is that the interviewees were not influenced by others and a disadvantage were that some answers may have been affected by the interviewee feeling stressed and therefore forced to give a response.

5.1.2 Affinity diagram

To organize all qualitative data the method Affinity diagram, also called KJ-method, were used, see section 2.3.1 Affinity diagram, page 6. In the first stage, the raw data from interviews and observations were filtered by extracting statements that could be potential issues and writing them down on post-it notes. This resulted in 300 post-it notes that was clustered into different categories. During the clustering, several post-it notes could be suitable within different categories. Some of the generated categories are therefor relatively close to each other.

The final outcome was seven categories i.e. seven issues. Each issue are consisting of sub-categories and are including more than one topic. Some categories had many post-it notes where data were repeated while other categories consisted of few notes. The number of post-it notes is not considered in this method. For example, 60 post-it notes clustered into one category were equally important as 15 post-it notes clustered into another category, since both created an own category. To achieve a wide range of categories and cover the whole spectra of information was more important in this aspect.

Organising and analysing qualitative data are time consuming. Identifying items from interviews and observations, put the items on post-it notes, group the 300 post-it notes into categories and naming these took around 80 hours for the researchers to perform.

Furthermore, if the same data would be structured by other people, they would probably end up with other categories. Even if the repeatability of the method can be questioned we believe that the generated categories are covering the collected data and are relevant since all of them were perceived as important among the participants in the prioritizing work shop, 2.3.5 Work shop, page 9. Moreover, to increase the repeatability, the methodology is thoroughly described in section see section 2.3.1 Affinity diagram, page 6.

We tried to make the groups equally "big" to not make any group bigger and therefore more important. When all post-it notes was clustered into the final categories, they constituted the issues. The naming of the issues should reflect the data connected to the categories. This resulted in general names to include the different sub-issues. The name safety was avoided within the name of a category, even if safety aspects was included in several issues. Using the name safety for naming the issue might have affect how people would interpret it, which might affect the prioritisation results.

5.1.3 Work shop

The purposes with the workshop was to rank the issues by importance and this was done by gathering people connected to the project, mainly the interviewees, to discuss and prioritize the issues identified. How this was done is presented in section 2.3.5 Work shop, page 9. It was important that the participants represented the areas R&D, logistic, manufacturing, production and safety. The main reason was that the opinions might vary between the different departments and affect how the issues were prioritized. Another reason is to be able to share knowledge during the discussions and to validate our findings. Unfortunately could not all participate during the work shop so there were representatives missing from some areas. To include them in the result, individual sessions were held where the issues were explained and prioritized. However, participants that had individual sessions did not have the opportunity to ask question to the experts within the different areas. The lack of possibilities to ask questions, join discussions and get inputs during the work shop, might have impact on these participants prioritisation.

5.1.4 Group constellation

In this study five different departments/knowledge areas was included. The choice of representatives have been shown successfully, since during the study and work shop they have manged to cover the different knowledge areas together. All department are connected to the project, except for the Logistic department. They have mainly contributed with information about the Born to Drive project since they are a stake holder in that project.

5.2 The three focus areas

The three focus areas that were chosen when investigating AT were AD, AGV and EOL, as stated in Figure 5.1. These areas were a good base for the discussions and a feasible representation of AT. The relations and differences between the three areas are discussed below.

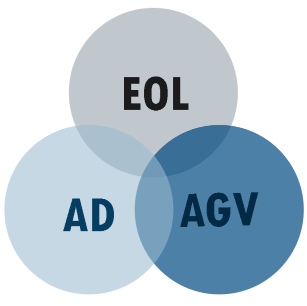

Figure 5.1: The three focus areas

5.2.1 AD-AGV differences & similarities

There are both differences and similarities between an AD car and an AGV. This is a question of interpretation. Several participants in the empirical study pointed out the differences between AD and AGVs but when discussing it further the similarities became clearer. The different context in which AD and AGVs are used may be the reason why people sometimes omits the similarities.

The difference between AD cars and AGVs can be seen as major since they are used for different purposes. If switching them, the similarities becomes clear ,i.e. if using an AD car in low speeds in a factory environment, does it not become an AGV then? Of course it is not that simple but there are clearly similarities.

In theory, both AD cars and AGV are automatic vehicles used for transportation. One of the biggest difference is that AD is supposed to have a driver or passenger in the front seat. This is however not the case for the FAP concept which means that car in FAP and an AGV is even more similar.

The approaches to safety are different when comparing AD to an AGV. An AGV have a very simple and general safety approach. For example, it stops for whatever comes in its way and if the object is not moved, the AGV will be standing there until the object has been removed. On the other hand, an AD car identifies and analyses its environment and take decisions of what to do in a more sophisticated way. For example, if a grit is passing close the camera, the radar will not confirm that there is an object in front of the car and it will not brake. For an AGV this is solved by letting a revolving safety radar spin at least two laps and only if the object remains it is seen as an obstacle.

The navigation is also different. An AD car navigates mostly with pre-scanned 3D maps of the environment together with GPS. An AGV either uses physical guidance, such as tracks or electric wires, or an indoor GPS system with reference points in the factory.

5.2.1 AD-AGV differences & similarities, page 43

5.2.2 AT in End Of Line

Using AD in unknown environments is a major contribution to the complexity of the AD technology and is one of the main challenges Volvo Cars is facing. However, when driving in a relatively restricted and known environment, such as a car manufacturing production plant, a large part of the AD technologies may not be applicable. The functions of an AD car developed for roads and urban environment cannot be directly used in the production plant because of the differences in environment.

The near future AD cars are primary developed and adapted to transport itself with a driver present. However, AT without a driver would be an enabler of cost reductions for handling cars in the EOL area. Apparently, the AD technologies or part of it must be adapted to the car manufacturing environment to enable AT in EOL. For example, the FAP function has been developed to be used in low speeds, without a driver and with both people and other objects close to the car.

5.3 Findings

This study have resulted in several findings where the overall purpose was to identify and analyse the main challenges of using AT in car manufacturing. The following identified issues and their importance will be discussed together with the possible benefits with using AT in car manufacturing.

5.3.1 The seven issues

In this section the seven issues presented in section 4.7 Issue presentation, page 38, are evaluated further. The issues are explained in a more detail, from different perspectives and with examples that represents the specific issue. A discussion about each issue is also presented.

Autonomous Guidance & Control: AT should be able to drive by itself in the factory without human interaction. To be able to navigate itself and determine when in time it shall move, the car must be supplied with necessary instructions and controlled in a safe way.

The navigation is according to R&D one of the main challenges of using AT in the EOL area. This is because the navigation system in an AD car cannot be directly used in a factory. AD cars uses GPS and pre-scanned virtual maps of the roads when navigating, enabling the AD car to recognize fixed reference points of the reality. To use the same navigation technology in the factory as on roads would not be possible because the GPS is not suitable to use inside the factory building[63]. There is however possible to use indoor GPS systems as the AGVs in Volvo Cars Body shop does. However, one drawback with the indoor GPS is that it often requires a revolving laser placed on a high position, above operators and machines in the factory. To scan the factory like the road environment is scanned for the AD cars would be possible but it requires a lot of work. This will however not allow bigger changes in the environment. Having a lot of different actors in may contribute to changes the environment making it harder or impossible for the car to recognize and localize in the factory. Therefor some interviewees had their doubts about the possibilities of using the same navigation solution as for the AD cars in a factory environment. Some interviews considered solutions for indoor navigation eve though that was not the purpose of the study. One solution discussed is to hard-code the path of the car. This is not a completely flexible solution but it will be quite easy to change. A solution for recognizing position was also discussed. If the car can recognize the surrounding or "look" at the floor. If having bar codes on a parking spot it would be able to tell when it have come to a specific position. The possibilities of using parts of the sensors and systems developed for the FAP function ma be an alternative as well. Navigating in the parking lot and finding an empty parking without human interaction has lots of similarities with the desired behaviour of using AT in car manufacturing.

It is desirable to have a flexible guidance of the AT cars. To have an indoor GPS system is generally seen as a flexible system since the reference points, because of their height, are seldom affected. It is however questionable how flexible the AD solution with 3D maps would be in the factory. Changes within the environment might result in an updated scanned 3D-map. Scanning is a major work and how often the map will be updated depends on how sensitivity the system is to changes in the environment.

Having a flexible AT system where the cars are not physically bound to a path the control of and communication to the car needs to be continuous and safe.

Compared to an AD car driving on roads, AT needs to be more accurately positioned since there are more narrow passages and stricter regulations in the factory. According to a AD technical expert at Volvo Cars an accuracy of an AD car in the Drive Me project of +-100mm is sufficient, but this may not be good enough in the manufacturing environment.

The information flow to the car needs to be well developed for AT. The AT car will need to know the next action to be able to handle all situations that can occur. For example, what to brake for, when to go and what tests that should be done. This control could be either centralized by some kind of control unit, computer or decentralized in each car.

Today all communication with the car goes through a manually connected device called IFLEX. This communication mainly includes diagnostic information transmitted to and received from the cars. Some interviewees claimed that making AT possible requires wireless communication for controlling and transmit instructions to the cars. Currently, there are projects at Volvo Cars aiming to develop a wireless communication with the car, which can be useful for AT.

From the safety perspective the car have to be able to diagnose itself at all times to secure that no errors occur while AT is used. For example, if the car is acting undesirable or deviate from the planned path, it must be able to detect it and stop. This diagnose status control requires continuous communication with the car during AT to assure that the car is safely transported. For example, only relying on the car to signal when an error occurs (e.g, flashing lights) can be insufficient since the signal system utilized in the car may not work.

Process Prerequisites: The design of AT and the process prerequisites in car manufacturing need to be balanced, both when it comes to process flow, factory layouts and technical aspects. There are precedence requirements meaning that some test stations have to be done before others. One example is that the air suspension, where the height of the car is set, has to be done before the Radar calibration as it is dependent on the correct height. If using the radar for AT this requires that the calibration has been performed before AT can be used. But if the radar is not needed for AT these prerequisites do not restrict AT in the factory. However some tests must be done in a specific order anyway. Because of the required calibration of some sensors it would be better to use sensors that does not need calibration before usage.

According to one interviewee there is a trend pointing towards sensors being fully calibrated already when delivered from the supplier. "I see a trend that modules are delivered with a higher quality from the supplier. Today we do not have to calibrate sensors that we had to earlier"[D4]. This means that the sensors will be calibrated directly when mounted on the car and some of the test stations may not be necessary any longer. An example is the rear view camera which used to be calibrated in the EOL before using it but is now calibrated directly from supplier. This is also the case for the ultrasonic sensors. They are calibrated directly from supplier. This may also be the case for the radar in the future.

In AT the driver is replaced by technology. Taking away the operator affects both the tests and the manual work within the EOL process and creates new prerequisites. Today many systems in the car is tested automatically by electronic tests. However, if a test requires that an operator inspects and evaluate the car's behaviour, this can be an issue if no operator is available in the car. Using AT in the test stations requires technology that is able to replace the operator and preform the tests at an equivalent level as the operator. The senses of an operator such as hearing noises cannot be utilized when AT is replacing the operator during tests. For example, in the roller bench and on the Short track the operator do not only drive the car but is listening for noise and feeling the driveability. This is a place in the factory where errors are detected every day meaning if taking away the operator this systems needs do be replaced or these errors will not be detected. It should be discussed if this manual tests are an efficient way to detect errors and investigate if there are any other way to do it in order to not hinder implementations of AT.

When the manufacturing of AD cars starts there will most probably be a mix of both AD and non AD cars. The mix of AD and non-AD cars will require the processes to manage a mix of both AT and conventional non-AD car transports. This is however also a question of which AD technologies are needed for AT, since the cars will be equipped with various levels of technology where some levels allowing AT and others not.

Interviewees have expressed that an external device can be a solution to include other cars than AD for the AT function [D1, D6]. Ff having an external device put on the car and no required sensor setup on the car enabling AT, it will be available for all cars in the factory. Otherwise it depends on what the customer have ordered. If using a part of the cars own sensor set up that is more often used on the cars the rate of cars that can be used for AT will be higher. An example of this is if using only the sensors supporting FAP which is a function with higher take-rate than AD. This function only requires ultrasonic sensors and camera. On the other hand if the requirement for AT is that it have to be a special designed AT car the rate will be lower. This means the mix and rate of AT enabled cars and non AT enabled cars needs to be considered. One must also have preparations for failure handling of AT.

Another possible issue in the process is the vehicle covers. In the last part of the EOL area a cover is put on some of the cars. This do not only protect the car it also covers most of the sensors lowering the level of available technology. The cover is not put on until the very last part of the EOL meaning that it is not a problem in the major part of the EOL area. This issue is bigger for the Born to Drive project since they are looking at the area after the point the car leaves the factory.

Dependability: The system for using AT in EOL must have a high level of dependability. Dependability is important for all kinds of self-driving vehicles since the control of the vehicle is given to the car, but for AT there is an additional aspect, it must be adapted to the factory environment. The car manufacturing is sensitive for disturbances, as mentioned in section 3.1.3 Robustness, page 18, and the AT-system must therefore contribute to an efficient production. The dependability for the system includes both availability and reliability of the AT function and the car.

The availability of AT is influenced by the design of the system and is a trade-off with system safety. This trade-off between availability and safety is also a challenge in developing AD cars driving on the road. If an AD car cannot assure safety, it will take itself to a safe stop meaning that AD will not be available. The reason is to never risk the passengers safety. It is likely that the first AD-cars will make these safe stops more frequently than AD cars in the later future. If AT is stopped frequently in the factory because of that the system is too sensitive with respect to safety, it will cause problems in the production flow. Therefore the demand on availability may be even higher for AT than for AD, which might require a evolving process to implement.

Reliability for AT is more focused on the product. Before AT all components of the car, and possible external components, must be assembled correctly and calibrated to assure that everything works as intended. If one part does not work as desired it may not be possible to rely on the AT-system. This means that the functions and systems in the car needed for AT have to be quality assured before AT can be used in a reliable way. Even though the reliability of AT is critical, some of the interviewees believed that using AT in the EOL area would be safer than having operators driving the cars.

Human-AT interaction: The operators working in the manufacturing environment and the AT technology can be seen as two different systems interacting with each other. Today operators carry out manual work close to the car in the test stations. These systems must therefore be able to communicate and understand each other in an efficient and safe way.

A concern stresses by the interviewees was that combining two different transportation systems can lead to problems. An example, when using both AGVs and forklift trucks in the same are, was brought up. The sensors on the AGV could not detect the forks on the fork lift since it only scanned the area close to the ground, which made them collide.

Therefore, it might also be a challenge to make humans and AT compatible, but due to other problems. How to develop the AT system to be safe enough is a challenge since safety and availability is a trade of and the manufacturing environment are sensitive for disturbances.

For the systems to work close to each other they probably must be aware of each other. The AT car must be able to detect and identify a human but the operators also needs to be aware of the AT car. Furthermore, it is important to recognize AT cars and also have sufficient knowledge about how they work to be able to understand their behaviour.

AGVs and other driverless machines working within the same areas as humans must have a safety stop. If there is a risk of an accident the AT car must be able to stop immediately. The future AD cars does probably not have an exterior emergency stops. If this is a requirement for AT to be utilized within the car manufacturing it has to be solved.

Today there are zones, fences and markings on the ground that regulates and inform people where to go and how to act in the factory. Of course it is possible to restrict the areas where the different systems are present, but this decreases the flexibility and limits the possibilities of using AT

Regulations: To be able to utilize AT in a factory environment there is a need of agreed standards and directives with regulations applicable to AT in the factory. There are standards and directives that defines safety requirements on, for examples, tools, vehicles and transports. One of the interviewees had knowledge about the use of such standards and directives within Volvo Cars and did not think that this case, using AD cars within a production environment is covered in the standards currently available.

AT is not yet formally defined and without such a definition it is not possible to know what regulations is applies to. Some of the interviewees thought that parts of the regulations in existing standard covers AT but must be updated so they are adapted for the use of AT within car manufacturing. The need of developing and establishing new standards was also mentioned among other interviewees.

There are standards and directives (all the discussed standards are presented in section 3.5 Standards and directives, page 26), covering vehicles intended to use on the roads,e.g., Motor vehicle and trailers (70/156/EEC) and Road vehicles - Functional safety (ISO 26262) and, for example the machinery directive addressing AGVs. However, standards addressing technologies similar to AT has not been found - is the car seen as a machine rather than a motor vehicle or vice verse?

Another question is what differs an AGV and a driverless AD car transporting itself. According to the Cambridge definition, a transport is defined as movements of people or goods from one place to another. The question is, can movements of itself be seen as transportation? Otherwise it is only a car driving by itself and that is not covered by standards for transports.

Another aspect is the age of the standards and fast developing technology. Many of the presented standards are relatively and since AD is a relatively new and fast developing technology, this can be questioned.For example, the standard for industrial trucks safety (SS-EN 1525) was developed in 97. In the case this standard would cover AT, it probably needs to be updated to cover the technical development since 1997.

Standard Road Vehicles - Functional safety 26262 is developed for functional safety of road vehicles in order to address the trend with increasing amount of complex software intensive systems, such as AD. However, this standard focuses on how to secure development of safety critical systems in vehicles when they are used on roads and is thus not applicable to AT.

The Swedish government are developing laws to allow self-driving technology to be tested on roads, for example, "The way to self-driving cars-for testing". This indicates a lack of relevant laws, regulations and standards addressing new vehicle innovations and technologies like AD.

In addition, there are requirements on tests that must be performed in the factory. These are specified in, for example, Technical Regulations, and affect the processes and tools in the EOL area. When introducing AT, these regulation must be considered and discussed. For example, in processes where there are requirements on testing driveability, AT may not be possible to implement as the tests needs to be performed by an operator.

Finances: The development of an AT system will require finances for developing the AT system and for the implementation in the factory. The challenge is to make the usage of AT profitable.

The factory environment as well as the technology might have to be adapted to fit AT. The changes in technology depends on the future AD solutions and if parts of the AD system used on roads (e.g., existing sensor and software) can also be used in car manufacturing. Moreover, changes in production of such as layouts and the process flow is also associated with costs. Thus, the cost will depend on how much that needs to be changed.

The benefits and possible savings must be analysed to know if AT is worth implementing. Implementing AT in EOL will lead to a lowered operator cost but it might also lead to benefits that is not directly connected to cost reductions such as safer systems and handling of cars that is more efficient and requires less space. A total cost analysis needs to be conducted to evaluate all costs and benefits in order to conclude if and when AT is worth developing.

The cost for developing an implementing AT in car manufacturing might depend on the proportions of the cars that can be used for AT within the manufacturing. If 10 % of the cars can be used for AT, it will probably not be profitable. The AT solutions should therefore strive to involve as big population of the cars as possible.

The first stage in the development of AD is not so similar to the scope in this study since it is developed for a certain type of environment and speed. In the future the AD cars will be developed for handling other situations that can be more similar to the scope. In that stage the chances of reusing the technology develop for AD are higher. The time can therefore be an important aspect for the financial of using AT in their car manufacturing.

The cost for using AT in the car manufacturing will be dependent on how AT is defined. If the AT will be defined as an AGV or as a self-driving car without a driver, the price for the insurance might vary.

The Born to Drive project may cover some of the financing part since they are investigating a similar case. If the solution could be used for both this project and the Born to Drive project it would improve the financing situation for the project.

AT-AD gap: An AD car is developed to drive on roads in high speeds and with a driver behind the wheel. AT on the other will be used in a factory environment in low speeds and without a driver. The different prerequisites for AD and AT creates a gap between the two when it comes to requirements on the behaviour of the technology.

The AT-AD gap is hard to define before the solution of AT is developed but some different aspects have been discussed during the study. AT will be used in low speeds with operators working in the same area, which changes the prerequisites for the sensors. The AT technology will have to detect and stop for items close to the car. This is an issue since most of the sensors are developed to be used for longer distances. There are also low range sensors on an AD car but they have a lower level of safety classification than an AGV. This means that it is necessary to develop the low range detection in an AD car and make sure that the systems and sensors have the required security classification in order to be used in the factory.

The AD and AT functionalists need to be separated in the car to eliminate the risk of enabling AT function when at the end customer. Similarly it is also important to prevent that the behaviour of full AD can be triggered unintentionally in the factory. This have to be assured in some way.

When using the AD function it will only brake for objects that are both detected and identified. If a person is standing in front of the car on a short distance, the car can only not "see" parts of the person. The the car will not be able to identify and will therefore not brake. When driving on roads this is not a problem since objects do not suddenly appear closely in front of the car as in a manufacturing environment.

If comparing AT with the type of AD used in the self parking concept, FAP, they have some similarities. Self parking is supposed to be used without a driver and in low speeds. Other types of sensors is used that are developed for short range usage. This means that FAP can be used in an environment where both objects and humans present close to the car. Apparently the gap between AD and AT varies depending on what part of the AD technology is used and what functions it is developed for. This is confirmed by one of the interviews who sees a big gap between AT and the first stage of AD but the gap between AT and the FAP concept is smaller. This gap between AT and AD may also decreased during development of AD. For example, the AD technology will eventually adapt to an environment with an increased number of objects and types of objects and the level of autonomous driving possibilities will evolve. This technology lies further ahead in the future and this development will most likely also improve AT and its capability of being used in the factory.

5.3.2 Result of prioritisation

The disagreement of the result varied between the seven issues 4.4. This difference in disagreement can be interpreted in different ways. The issues with a high disagreement are recommended to investigated further. There are no obvious correlation between a high priority and a low disagreement but for the two issues with the highest priority, the disagreement are low. These two issues are with high certainty important for Volvo Cars to start working with to enable AT in EOL.

However, the total score does not show if a participant was given all 100 points to the same issue, which would have had a huge impact on the diagram. Therefore the next diagram presents the points distribution for each participant, see Figure 5.2

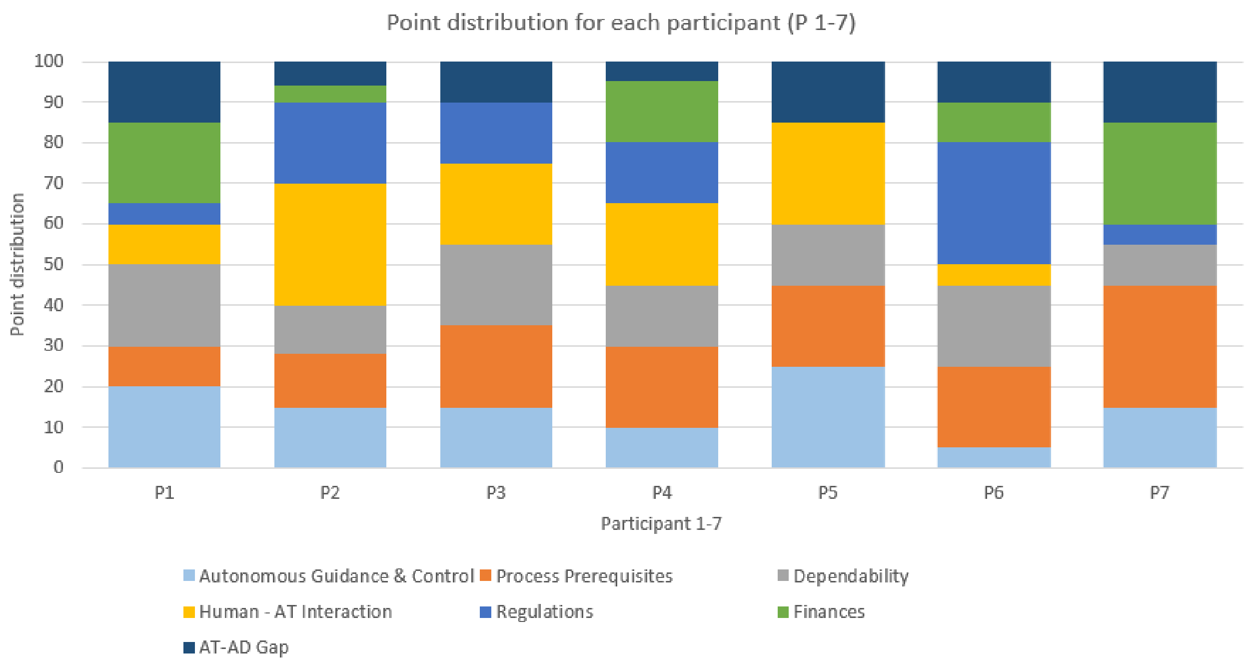

Figure 5.2: Point distribution for each participant

On the x-axis, the seven participants are presented (P1-7) and the y-axis are showing the number of points (100p) the participants distributed between the issues. The size of each colour in the graph represents the points given for each issue by the participant. Some person have distributed their points relatively equally between the issues. Other have given some issue high importance with 30 points as a maximum and other issues no importance since zero point were given.

The diagram shows how each participant have distributed their points. For example, if one participant had assigned all 100 points to the same issue this would have been reveled in the graph presented in Figure 4.4.

When comparing the different sizes of the same colours it is clear how much the size of the points given to the same issue are varying between the participants. The green colour is representing Finances and is highly varying in importance between the different participants since it have been giving both high scores and zero points. Dependability, on the other hand, represented by the grey colour, is varying less in importance compared to Finances. For example, Participant 7 think that finances is of high importance while participant 3 thinks this issue is not important at all since it were given zero points. This is also reflected in the 4.4.

The interviewees have been guaranteed anonymity and therefore are the result presented in Figure 4.4 not connected to a person or a department.

It would be interesting to analyse how the participant distributed their point depending on what department they belong to. Do they think their own area is of more or lowest important than the other? During the interviews several people tend to mention the main issues to be within other areas than their own. The worst case would be if the expert within a specific are mentioned the main issues to be within his or her own area, since we suppose the expert to have most knowledge about the possibilities. In this study there were only one or two representatives from each department, therefore an analysis like this was not possible. The deviation could be due to either individual opinions or due to different work expertise. If involving more people one could analysed if this deviation in opinion was connected the departments the participant worked within.

When the result in Figure 4.4 was presented for the participants the most common reaction was that the importance between the issue is surprisingly even. The method were questioned since the participants had the opportunity to divide their point freely between the issues. This might be one reason that the total points were that evenly distributed between the issues. The result might have looked different if each participant only were to choose the top most important issues

The graph presented in Figure 5.3 have been recreated from the data collected during the work shop. We assumed that the issue with the individually highest points would be mentioned to be the most important. Note that the participants were never asked to do this top voting. The ambition was to collect the three highest scores from each participant but in the case where the points was divided equally between some issues only their top two votes were used.

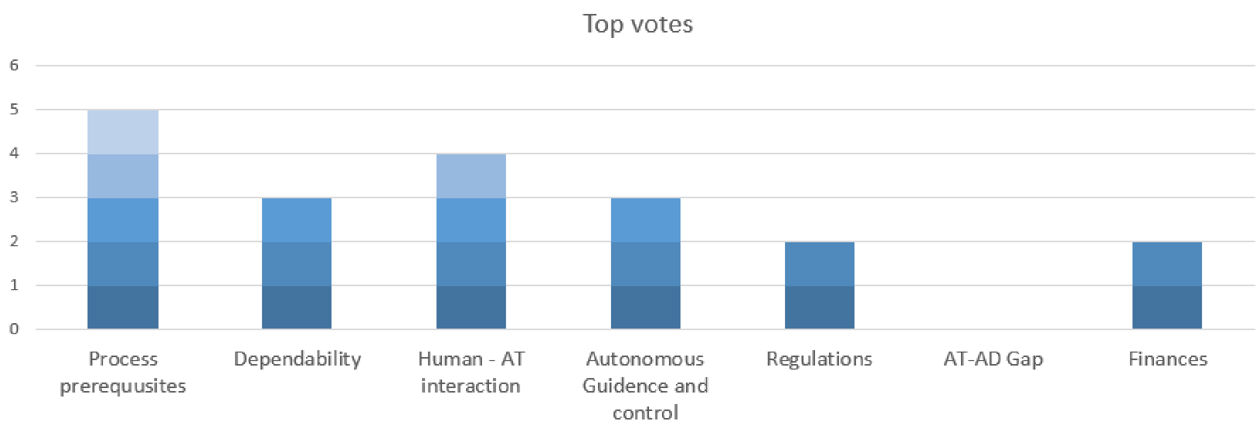

Figure 5.3: Prioritisation participants top votes

The top voting results shown in Figure 5.3 seems to follow the result in Figure 4.4 relatively well. Thus, it can be concluded that the issues perceived as most important among the participants are well represented in the graph shown in Figure 4.4 and that the possibility for people to divide their 100 point freely between the issues, were not the cause to the relatively evenly result.

5.4 Future Work

This study is the first step towards the use of AT in Volvo Cars's factories. The issues of using AT in car manufacturing are based on the interpretation and definition of AT used in this study. Since AT is not formally defined it would be preferable to discuss and agree upon a definition of AT across all stakeholders as a first step. Then it would be easier to discuss future possibilities of AT in relation to the findings presented in this study.

The findings presented in this study should be further investigated in order to develop and assess candidate solutions for efficient use of AT in car manufacturing. The findings from the Born to Drive project should also be included in the investigation to make sure no important information have been overlooked.

Future work should also include building consensus on an inter-departmental level of what parts are most important to deal with first. That work can be based on the results from the issue prioritisation reported in this study. One recommendation is to gather a cross functional team, with representatives from the five areas presented in this study, when investigating AT further. This is important since this study indicates that people at different departments have different perception when it comes to information related to AT. An all aspects are of value.

It is also necessary to investigate the profitability of using AT in car manufacturing. In this investigation, results from the Born to Drive project and the technical development of AD systems should be considered. As the technology evolve it may be more mature and easier to implement in the factory environment in the future, which in turn can decrease the development and product cost for adapting the AT system to car manufacturing.

Usually new technologies, such as AT, mature over time concerning reliability and availability and thus the implementation of AT should be an evolving process rather than a big bang. In practice, it may start with implementation and assessment of AT in part of the EOL area or in dedicated test stations (e.g., one roller bench).

5.5 Validity evaluation

Validity can be described as an assurance that the right thing is measured and to what degree the results of the study is connected to reality [47]. In qualitative research the relevance of validity can however be discussed [11]. Measurements are not often a significant part of qualitative studies and therefor that type of validity have little bearing in these studies [11]. In this study the focus therefore lies in how the study is connected to reality.

Validity can be determined by discussing the study in relation to the four areas Construct Validity, Internal validity, External validity and Reliability [68].

Construct Validity: This part of validity concerns constructing the right data measurements for the study [68]. It is important that the researchers perform a "subjective" study and to continuously counteract bias [68].

The literature study was conducted to make sure the researchers had sufficient background knowledge before designing the case study. In the literature study different sources for information were used in a high extent to validate the information. The background knowledge were needed when designing the interview guide. The interview guide was in turn discussed and confirmed by the supervisor at Volvo Cars before conducting the interviews. This was done to make sure that the questions were asked to get the right information.

In this study several well established methods and frameworks have been used. Before choosing a method several similar alternatives were investigated to be able to choose the method most suitable for this study. The well established methods have also been strictly followed. To counteract bias by the researchers, observations and coding were done by both researchers in parallel without discussion. After this the results were compared and the common themes were said to have a higher level of validity.

In the work shop the seven issues were verified by all departments participating in the study. This was a way to find out if all departments felt that their issues were covered by the seven issues. After the seven issues were found a table was created showing what departments that had mentioned the issue already in the interview. If an issue was mentioned from by several persons during the interviews this validated the data further.

Internal Validity: This part of validity concerns the establishment of casual relations [68]. This is of high importance in explanatory case studies when trying to explain for example how and why X leads to Y [68]. This case study is exploitative and the internal validity is therefor just discussed based on the effect of the level of interference by the researchers.

During observations both non participation and participation observations have been conducted. By performing the non participation observation first the researchers got a good picture of the situation before the operators were aware of the observation.

It is hard to counteracts the interference of the researchers in interviews. There is a risk that the interviewees do not express their opinions because feeling restricted by the recording or unwilling to tell their opinion. Guaranteeing the anonymity of the participants was a way to limit this affection. Since the purpose of the interviews was to get the interviewees perspective the researchers also emphasized that there were no right or wrong answerer.

External Validity: This part concerns establishing a domain where the study can be generalized [68]. In this study a single case study have been conducted. This limits the level of generalization of the study which means that the same results may not have been found in other contexts. However the case study were conducted at one of the leading vehicle manufacturers in Sweden. The company have broad knowledge of both manufacturing and AD technology and this should strengthen generalization of the findings and give a good representation of at least the automotive industry.

Reliability: This part concerns establishing an assurance that the operation of the study could be repeated with the same result [68]. Data becomes reliable if it can be replicated, this is a difficult criterion to meet in a case study since it is not possible to “freeze” or repeat an exact social environment [11]. In this case study all activities have been documented for another researcher to be able to repeat the same study in the best possible way. The empirical data could vary due to personal opinions but if interviewing people from the same departments as in this study, we believe that the result will be about the same. The presentation of the result may be different due to the researcher personal interference but the result would probably cover the same areas.

If a more reliable study is needed, the same methods and data presented in this study could be used but in a lager extent. It would be good to collect data from several persons within the same department at Volvo Cars to investigate if the opinions are common within the departments and therefore representable for that department.

6 Conclusion

The purpose of this thesis was to identify and investigate the main challenges, assess their importance, and analyse and discuss them in relation to relevant literature. The result of this thesis is seven identified and prioritized issues. These were identified by using an empirical case study methodology applied to Volvo Cars Torslanda. It is shown that all issues are of importance and that they give a good representation of the challenges using AT in car manufacturing. These seven issues are:

1. Process Prerequisites
2. Dependability
3. Human - AT Interaction
4. Autonomous Guidence and Control
5. Regulations
6. AT - AD Gap
7. Finances

The importance of the issues was investigated in a workshop were the participants prioritized each issue, according to what issue is most important for Volvo Cars to start working with. This resulted in the top-three issues Process Prerequisites, Dependability, and Human-AT Interaction. Even though there are some disagreement in the priority among the participants there are no indication of relation between the level of disagreement and the level of points distributed. This indicates that all issues are important and can be base to agree upon an agenda for further work.

To be able to develop a successful AT system at Volvo Cars the knowledge received from this study as well as other projects mentioned, such as Drive Me and Born to Drive, should be used. To involve all departments related to AT, make sure to have a clear communication and share the knowledge, will increase the chances of covering all aspects of the challenges using AT in car manufacturing, before searching for and developing solutions. This is of importance since different departments have different perceptions of the issues. Understanding of the issues is shown to be enriched among participants when discussing the issues with each other.

A definition of AT is suggested in this thesis but needs to be further elaborated in order to set the baseline and pave the avenue for subsequent development and implementation of efficient solutions for the issues reported in this thesis.

The AD technology really is in the spot light within the automotive industry and is a fast developing area. In a couple of years there will be a greater proportion of cars equipped with AD technology and the functions will be more sophisticated. The issues identified in this study may therefore change. For the specific case at Volvo Cars it is important to monitor the advancement of AD technologies in order to take advantage of this and achieve efficient solutions for using AT. Furthermore, the AT system shall preferably be developed to include as many cars as possible. If AT is developed on basic systems, the usage of AT will be applicable to a larger population of cars, which improves the business aspects. This increases the chances for AT being worth implemented within car manufacturing.

This study is the first step towards using AT within car manufacturing and have shown that there are several benefits. It have also shown a number of issues characterizing the main challenges.

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A Appendix

Interviews will be held with:

1. Manufacturing engineer with technical expertise
2. AD expert with technical expertise
3. Safety expert for the factories
4. Yard logistic operation managers with knowledge of born to drive
5. Production expert with knowledge of the EOL processes

Purpose with the interviews

There are two main purposes with the interviews.

1. Collect the information needed for us to identify challenges and issues with utilizing AT in car manufacturing.
2. Identifying challenges and issues from all the different areas.

Introduction

Purpose:

1. Explain the purpose with the interview.
2. Explain why he/she is participating as an interviewee.

Secrecy:

1. Explain that all information given by the interviewee will be treated anonymously in reports and papers.
2. Make a decision of how to refer to the interviewee anonymously.
3. Explain that the answers from the interviewee will only be treated by researchers and supervisors involved in the study.

Involved parties:

1. Supervisor at Chalmers, Åsa Fasth Berglund
2. Supervisor at Volvo Cars Joakim Pernstål (81412)
3. Master thesis worker Louise Alinde Sundbeck
4. Master thesis worker Josefin Karlqvist

Procedure:

1. One is asking the interview question and the other are asking additional questions
2. Inform the interviewee that the same interview guide are used for interviews with other interviewees and that can be a reason that not all questions are directed to their area of knowledge. It can therefore be hard to answer some questions. There are no right or wrong answer and their input or view is always of interest.

3. Inform the interviewee that he or she always are allowed to interrupt if some question is unclear.

Presentation:

1. Present us
2. Present the definition AT, project and the expected outcome which is to generate theories and hypotheses for issues and problems.

Permission- recording:

1. Ask for permission to record the interview. Explain that the purpose is for us to be able to go back if we do not remember.

Introduction questions

1. Name?
2. Organizational affiliation?
3. Current position?
4. Time at current position?
5. Experience of current working area?
6. Time at Volvo Cars?

Interview questions

1. What are the possibilities and limitations using AT within car manufacturing ?
2. Where is it possible or not to use AT within a car manufacturing?
3. *Present the EOL area and the processes.* This is the area we are analysing. What potentials do you think there is when it comes to use AT? Where is it most suitable?
4. Which characteristics does a car need for the use os AT?
   (a) To replace the operator*(senses, actions, knowledge)*
   (b) What are the differences between an AD car and an AGV?
5. What could your department do to improve the possibility os using AT in the Volvo Cars factory?
6. What can the other departments do to improve the possibilities of using AT in the Volvo Cars factory?*(Safety, Production, Manufacturing, technical and Logistic)*
7. What three main challenged of using AT in production do you think there is?
8. How do you think these challenges shall be solved?
9. Do you want to add something?