Autonomous Transports in Car Manufacturing

Master’s thesis in Supply Chain Management and Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report no. E2023:107

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A Case Study of Volvo Cars' End of Line Manufacturing process in Torslanda

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Cover: Volvo vehicle

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Abstract

Volvo Cars is working with continuous improvement thus looking to optimize every process in their operation in an efficient manner. This thesis investigates the utilization of Volvo Cars´ self-driving technology in their vehicles for Autonomous Transports (AT) focusing on the aspects, on-board and off-board sensing. The vehicles are currently manually transported by operators from the factory out-bound port to the parking yard, with the objective to transition the operation to an automated system. The research methodology used in this thesis consists of an empirical study including observations, interviews, data triangulation, workshop and data analysis and a literature study. The findings indicate that an off-board solution would be preferable due to the technology addressing the challenges that Volvo Cars is today facing which primarily consists of vehicle covers that limits the cars sensing capabilities. However, the off-board solution is a short-term solution because Volvo Cars long-term goal is to fully use the vehicles' on-board autonomous driving capabilities for transporting and parking vehicles. This would lead to reduction in operational costs, minimizing emissions and improving safety. However, the implementation of autonomous transports poses challenges that need to be addressed such as fulfilling cyber security demands, standards, and regulations. This thesis concludes that AT have a high potential of transforming the hazardous tasks in automotive industry for the operators into a more safe and sustainable work environment while simultaneously optimizing their operation. Moreover, the transition from manual to autonomous transportation would provide Volvo Cars with competitive edge within the automotive industry.

Keywords: Automotive industry, Autonomous transports, Outbound logistics, End of Line, Autonomous drive, On-board sensing, Off-board sensing

Acknowledgements

We would like to express our outmost gratitude and appreciation to everyone that supported us throughout our thesis. Firstly, we would like to thank our supervisor at Chalmers University of Technology Abdullah Sultan Farook for providing us with support, feedback, and guidance throughout our research at Volvo Cars. Your expertise and knowledge have been valuable for both me and my thesis partner, we could have not finished the thesis without your help. Alongside our supervisor at Chalmers University of Technology, our examiner Robin Hanson which also has the knowledge and expertise within the area has helped guiding us, we appreciate your unwavering support and motivation for us to keep moving forward. Additionally, we would express our outmost appreciation to Joakim Pernstål, Teuta Qorri and Sophia Wetterberg that has been our supervisors at Volvo Cars, your experience, knowledge, feedback, and guidance has been crucial for us to finishing our research. We would additionally like to extend our appreciation to all the participants that took their time to share their insights and experiences with us, without your contribution we could not have shaped the case study. Furthermore, your insights have been undoubtedly impactful for our thesis. Finally, we would like to thank both Tony-Michael Andersson and Joakim Pernstål for both providing us with the opportunity to conduct our master thesis at Volvo Cars and using their resources and facilities to complete this thesis.

List of Abbreviations

AD - Autonomous Drive
ADAS - Advanced Driver Assistant System
AGV - Automated Guided Vehicle
AT - Autonomous Transports
AV- Autonomous vehicle
CCN - Convolutional Neural System
EOL - End of Line
FC - Factory Complete
FMWC - Frequency-Modulated Continuous-Wave
GNSS – Global navigate satellite system
IEA – Infrastructure enabled autonomy
IMU - Inertial Measurement Unit
OBL – Outbound logistics
RQ - Research question
SLAM - Simultaneous localization and mapping
V2G - Vehicle-To-Grid
V2I - Vehicle-To-Infrastructure
V2P - Vehicle-To-Pedestrian
V2V - Vehicle-To-Vehicle
V2X - Vehicle-To-Everything

Disclaimer: Volvo Cars will be referred to as Volvo.

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1 Introduction

As cars' automation technology constantly develops for commercial applications, it also creates a possibility to utilize the automation technology in a manufacturing setting to the company in question. However, adapting the technology, in terms of AT, in a production system entails multiple challenges that need to be addressed. An example to this, is Volvo Cars' interest in implementing AT in the car manufacturing environment i.e. the product transports itself throughout the production. By utilizing the vehicles self-driving technology, the vehicle can drive to designated areas without an operator present in the vehicle. There are two methods of approach, commencing, on-board technology is referred to as the approach with the use of the internal sensing technology in the vehicle for the benefit of AT. While the off-board technology refers to external guiding systems to support the AT functionality of a vehicle where the car is regarded as blind with the assistance of communication networks. According to Liker (2021), this has the potential to improve the manufacturing efficiency by eliminating waste in terms of time e.g., unutilized resources of operators where they spend time moving in and out, thus not being a value adding activity, of the vehicle when transporting it. Cost savings can be defined as the process of decreasing expenses or expenditures that an organization, company or individual incurs through an implementation of various methods, such as enhancing process efficiencies, optimizing operations, and utilization of resources. In this case, the implementation of technologies for minimizing costs and enhance profitability, leading to freeing up resources for other purposes. By introducing an automated system, this time waste will be eliminated, an area of which Volvo Cars are interested in researching in their End of Line (EOL) of their production.

A previous study which is a pre-study conducted by Karlqvist & Sundbeck (2016) at Volvo Cars concluded that the combination Autonomous Drive (AD) and Automated Guided Vehicles (AGV) technology are compatible to develop a feasible AT technology within the production. In addition, the study also states that there are seven main challenges of implementing AT in production of which three were of highest importance: Process prerequisite, Dependability and Human-AT interaction. The remaining four were: Autonomous Guidance and Control, regulation, AT and AD gap and lastly Finances (Karlqvist & Sundbeck, 2016).

This case study will be performed at Volvo Cars and addresses the research questions regarding AT in car manufacturing. The key areas that will be researched are the use of AT in a manufacturing setting, in this case a manufacturing plant. The difference between this study and the study made in 2016, Challenges of using Autonomous Drive technology for Autonomous transport in car manufacturing (Karlqvist & Sundbeck, 2016) is that this case study will look at the most suitable and candidate solutions.

1.1 Background

Autonomous vehicles consist of functions such as planning and control, localization, perception and management. If the vehicle is connected to the infrastructure, e.g. satellite connection, to retrieve information of its surroundings, a prerequisite to localization and perception, it is termed as an autonomous vehicle (AV). However, depending on the vehicle's technology the level of automation differs (Faisal, 2019). By the year 2030, Litman (2023) predicts that autonomous vehicles will be sufficiently dependable in the sense of substituting human driving with the advantages of safety, efficiency and increased productivity thus resulting in cost reduction. However, Litman (2023) states that there is a considerable uncertainty to this statement due to unknown measures of handling contingencies e.g., unstable wireless connection and weather conditions.

Volvo Cars, a Swedish automotive company owned by Geely Holding Group, is one of many companies that is adapting their vehicles towards autonomous transport, as it is believed to become the next frontier, mainly to increase safety which is one of Volvo's highest values. Volvo is set to generate a third of annual sales from fully autonomous cars in the middle of the next decade, providing increased traffic safety, improved environmental footprint, convenience e.g., allocating your time to something of a more importance such as work-related activities etc. (Volvo Cars, 2023). In addition, the fully autonomous technology can also be operated as a commercial vehicle to provide e.g., freight, taxi, and bus services (Faisal, 2019). Furthermore, Volvo currently uses level 2 automation in their cars today. Level 3 has been skipped due to the gray area of which party is responsible in case of an accident on the account of jurisdictional issues (Volvo Source, personal communication, 2023). Moreover, level 5 automation is not applicable today due to legalization, ethical aspects, infrastructure, cooperative traffic management, production costs and other political measures (Martinez-Diaz & Soriguera, 2018). Fully autonomous vehicles are classified as Level 5 automation (level of automation is described in Table 1) (Faisal, 2019). According to Saeed et al (2016) highest level of automation is defined as: "*The vehicle is intelligently designed to monitor roadway conditions and act solo, performing all safety–critical driving functions for an entire trip (a fully driverless level)*", providing advantages such as improved fuel economy, lowering the risk of collisions including the severity level and also safe transportation if the driver were to be tired or too intoxicated to operate the vehicle etc. (Saeed et al., 2016). However, the commercial application is predicted to be limited in the early stages of the launch e.g., due to inclement weather and unmapped roads of which the vehicles are unable to handle (Litman, 2023).

In relation to this, Volvo wants to exploit the autonomous technology in their production to improve productivity and lower cost by eliminating time waste of using operators and thus potentially produce more vehicles (Hjalmarsson-Jordanius et al., 2018). As of today, operators transport the vehicle after it is produced throughout the rest of the production phases including parking (Volvo Source, personal communication, 2023). Thus, the use of the technology has an application in the EOL of Volvo's production where the cars will autonomously execute the parking in the yard after being factory complete (FC). However, there are no published studies up to date on using only onboard sensing technologies i.e. purely adapting the autonomous driving technology of the car itself in a manufacturing setting without using external guiding systems. Thus, the objective with this study is to, through different methodologies, identify the opportunities, challenges, and possible solutions for such implementation.

Table 1*: Level of vehicle automation (Faisal, 2019)*

Level of automation	Automation technology
Level 1	Driver Assistance: Adaptive cruise control including braking and acceleration
Level 2	Partial Automation: lateral and longitudinal control i.e awareness of the surroundings with response to steering, acceleration, braking.
Level 3	Conditional Automation: The vehicle can operate independently with the condition that the driver is required to take over when requested i.e. limited disengagement from the vehicle.
Level 4	High Automation: The vehicle is fully autonomous and capable of handling all driving functions and monitoring the driving environment. The driver is requested to take over if the vehicle reaches its operational limits e.g. heavy snow.
Level 5	Full Automation: Fully autonomous. No driver required behind the wheel. The vehicle can be operated without a steering wheel or gas/brake pedals.

1.1.1 Current production state at Volvo Cars Torslanda

When the car is fully assembled it is transported from the assembly line into the first EOL stations where software download, and electrical checkout test are carried out. The software is downloaded, and electrical checkout test is performed to see if the cars functions are working as anticipated. Thereafter, an operator drives the car manually through different test stations, and if the car passes all tests, it is labeled as FC. Once the car is FC it either receives a vehicle cover (dependent on targeted market or weather conditions) then driven out or is driven out directly without a cover by an operator into the parking yard to a designated parking space based on the car's customer destination. This process is illustrated in Figure 1. The focus area of this study is framed in Figure 1, which is FC to the parking stage including the cars with vehicle covers. The objective is to provide solutions for the end stage of the EOL where the vehicles will perform self-parking in a safe and cost-efficient manner.

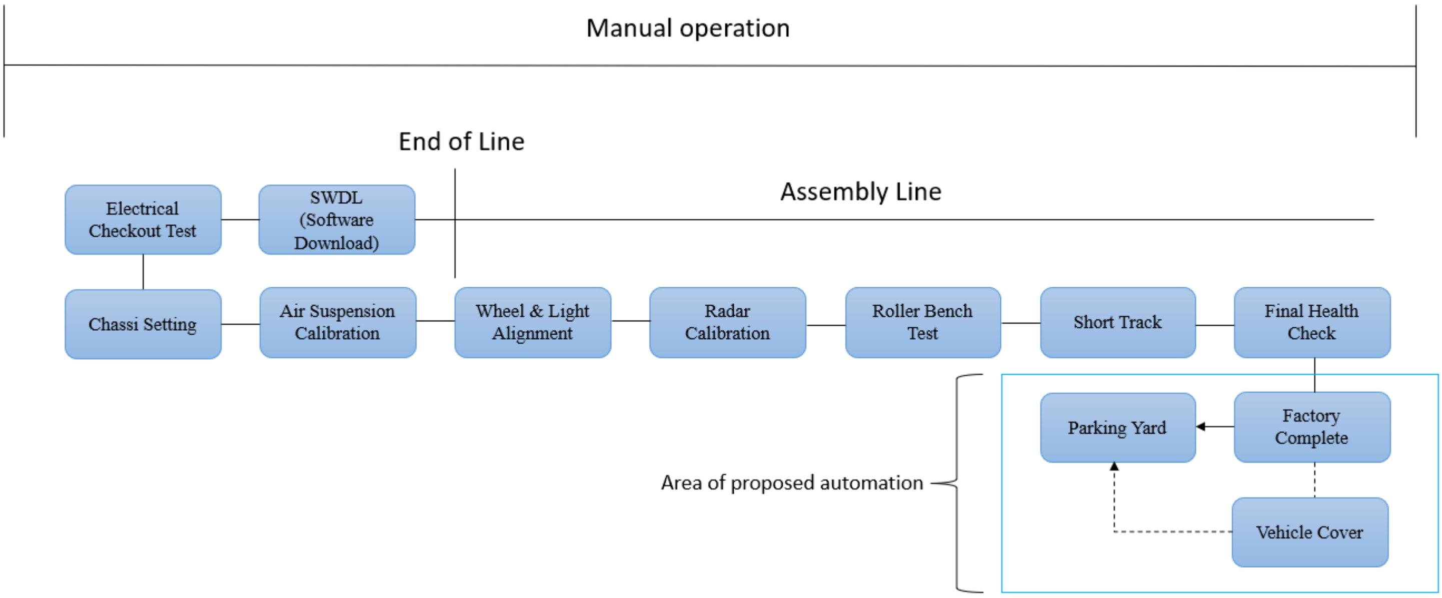


Figure 1*: The EOL process and the proposed automation area*

The parking yard operation at Volvo involves four operators each shift (there are three shifts) who are responsible for transporting vehicles to their designated parking spaces. This is in addition to other operators who perform different tasks in the parking yard. The cars are driven out of the outbound port by a single operator at a time, with a flow capacity of two cars moving in parallel. As the cars are being moved to a parking area, two operators get ready to transport two additional cars that are being released from the factory. Once the initial set of cars have been parked, another operator transports them back to the outbound port to repeat the process, as shown in Figure 2, where the dotted lines signify the non-value adding return path.

The yard operation also includes other type of factors that affect the implementation of an autonomous solutions and compromises the safety of those. These are the external actors e.g. trucks who loads the cars, internal transportation of supervisors and other operators, separate flows that requires manual handling e.g. damaged cars and lastly pedestrians who either operates in, or crosses, the area. Thus, Volvo want to implement the autonomous transport to a specific area in the yard where the risk of interacting with the different factors is considered low as an initial phase. Figure 3 is a satellite image of the focus area in parking yard and will be defined as Stage 1 of the autonomous transport implementation.

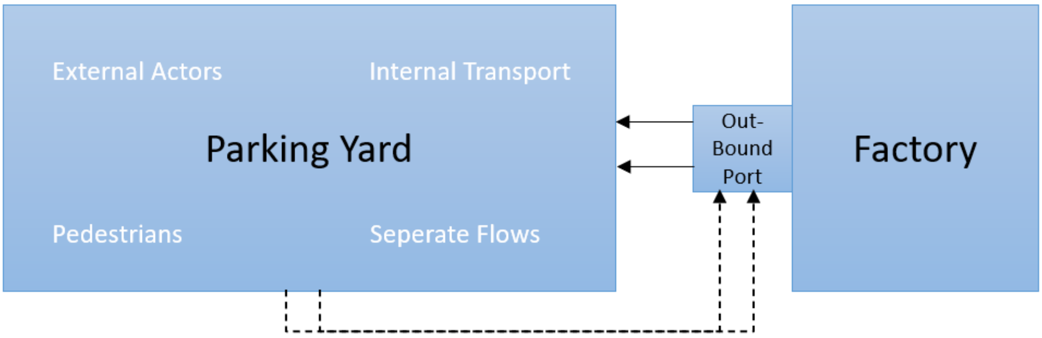


Figure 2: *Parking yard operation*

Figure 3: *Delineated satellite image of Volvo's parking yard with the outlined focus area (Stage 1)*

1.2 Purpose & Research questions

According to Karlqvist & Sundbeck's (2016) recommendations for future research, it was stated that further research must be done regarding automation solutions in factories. Thus, the technological requirements and their feasibility in the Volvo production must be studied to provide a solution. The purpose of this study will be an extension to that report where the key research area will be utilizing the existing self-driving technology in the vehicles and if other solutions regarding external guiding systems are required or preferable. This will take place in Stage 1 of the EOL, where the objective is to present different feasible solutions, with constrains considered, such as safety and quality. The solutions effect on the productivity will also be taken into account. Thus, the research questions (RQs) are the following:

RQ1*: What technological solution are most suitable for implementing AT in Stage 1 and what constraints exist?*

RQ2: *What effects would an AT solution in Stage 1 have on productivity in terms of takt-time and cost savings, and safety?*

1.3 Delimitations

To provide the case study with results in relation to the RQs, the delimitations below must be put in place to carry out the project. This is due to time constraints and the following delimitations in Volvo Cars request.

- This case study will be conducted at the Volvo Cars Torslanda plant.
- The focus area at the plant will be at the Stage 1 in the EOL where the finished cars are being driven out and parked.
- Implementation of the solution will not be included in this study.
- This case study will not delve into the technologies of vehicle automation solution, only present an overview.

2 Methodology

This chapter describes the approach towards data collection, qualitative and the analysis of it to address the research questions. The empirical study will be supported by a literature study of the research area. Figure 4 illustrates an overview of the expected timeline of each phase throughout the project and is explained further in the sections below.

2.1 Research design

The overall research strategy in this study is based on a case study methodology using qualitative data (Yin, 2018; Bryman & Bell, 2015) which consists of two parts, a literature and an empirical study of which are almost executed simultaneously throughout the project, with exception of the literature in the beginning of the project with the objective to acquire knowledge to support the empirical study. Initially a search for similar projects were conducted to help set a foundation for the project and a pre-study by Karlqvist & Sundbeck (2016) was identified on challenges of AT in car manufacturing. The objective is to obtain knowledge about the theoretical and practical possibilities for implementing AT in Volvo’s production through *interviews, observations, internal documents and cases, pre-studies, data analysis, evaluation* and *workshops*. The different data collection methods are used to provide in-depth understanding of different perspectives, both tangible and intangible. All methods and literature were considered in terms of ethical conditions and validity and reliability which are presented further in section 2.4 and 2.5.

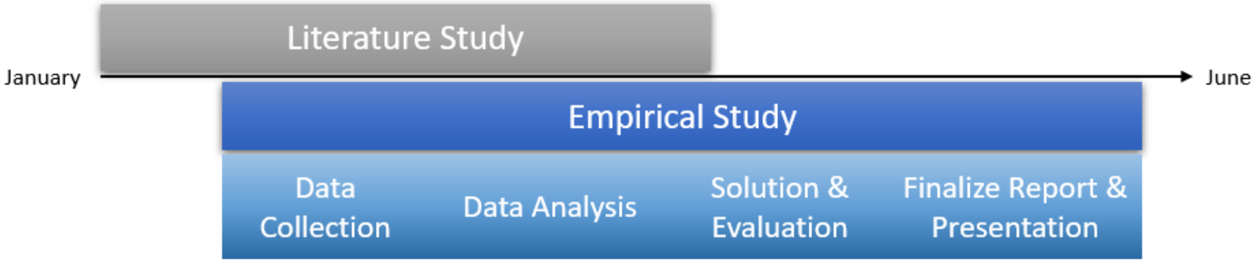


Figure 4: *Research timeline*

2.2 Literature study

The research design starts off with a literature study. The objective is to gain a knowledge overview of how an autonomous vehicle functions which includes its sensing technology, cognitive function and also how it communicates with other vehicles and infrastructure technologies. Furthermore, infrastructure technology that has the possibility to guide and navigate autonomous vehicles that suits Volvos standards, in terms of safety, reliability and cost, will also be researched. In addition, a related work regarding implementing AT in the automotive industry and general challenges of AVs was presented as a foundation, together with the data collection, for recommendations on future research. The literature study will be conducted by searching on keywords for the project which is provided in Table 2 below.

The authors Bryman & Bell (2015) also suggest that using a wide range of databases could be beneficial to identify a variety of different papers. To obtain base knowledge a literature review was conducted with the purpose of understanding keywords of the project. The purpose of doing this is to build on the already existing data regarding the challenges of implementing AT thus getting an insight on methods, theories and strategies that are possible to use in a project (Bryman & Bell, 2015). However, it is important to be critical of the information retrieved because sources can be biased thus affecting the results when comparing (Bryman & Bell, 2015).

Starting off with keywords such as *automotive* were searched on, without using any Boolean operators. Thereafter, with the base knowledge the keywords were expanded using the Boolean operators, and searches such as Autonomous transport were discovered. The keywords were used with the combination of Boolean operators such as, “AND” and “OR”. This is done to not miss any important literature that will come to use. Combining the most relevant keywords with each other resulted in the keywords presented in Table 2. Furthermore, following databases were used: Google scholar, Emerald insight, Science direct, eBook Collection, Chalmers Library, IEEE Xplore and Scopus.

Table 2: *Keywords for the literature study*

Car/Vehicle Manufacturing	Automated Guided Vehicle
Autonomous Car/Vehicle	Autonomous Drive
Car/Vehicle Production	Self-driving car/vehicle
Autonomous Transport	Automotive
Lidar system	Automotive radar
ADAS lidar system	Ultra-wideband system
Simultaneous localization and mapping	ADAS vehicle
Parking sensors	Autonomous car/vehicle system architecture
Indoor positioning technologies	Infrastructure enabled autonomy

2.3 Empirical study

Volvo has made it possible for this thesis to use their resources such as the Torslanda plant, observation of the production, employees to interview, documentation of prior reports, workshops and agile teams to provide information/help if necessary. In addition to that, internal documentation was provided regarding similar cases, production layout, EOL path, process description, system and function specification. The literature study and the analysis of it is expected to be carried out in parallel to the interviews to provide a better investigation and insight in the sense of linguistic and contextual understanding. This would also result in new topics/subjects to be investigated for the benefit of the researchers.

2.3.1 Observation

Observation is a valid method of gaining contextual understanding when combined with other research methods (Hennink, 2011) such as a brief literature study. It is also important to know when to and how to observe, it could be through recording, assistance of a visualization system or by watching. Two mainly used types of observation are participant and non-participants observation where the non-participants blend into the background. Whereas participant observation means that the researcher is involved in the activities. This thesis will use a non-participating observation approach due to not having intense involvement in the day-to-day activities (Hennink, 2011). Observation in factory settings is important for the researchers to visualize potential solutions based on the environment such as the physical constraints. The physical constraints could be lines on the ground for the sensors to follow and walls or passing objects in the same route that could cause risk for collision.

2.3.2 Interviews

According to Lüders (2001) the most common type of empirical data collections are observations and interviews. There are multiple advantages and disadvantages for interviews. The interview type used in this study will be a semi structured interview due to it enables more explanation rather than close-ended answers. A semi-structure could be effective due to open conversations and possibilities to follow-up questions that is not a part of the interview guide, thus might provide additional information. This could also occur while the interviewee describes an area, and the researcher is given the possibility to ask questions. In addition, a semi structured interview is ideally better if more than one person is conducting the interviews, which is of preference (Bryman & Bell, 2015). This suggests that an interview guide should be prepared for the interviewees with the help of Bryman & Bell (2015) and the research questions chapter resulting in the questions in Appendix A.

Qualitative research focuses on describing, explaining and interpreting data. According to Willams (2007), "*One identifier of a qualitative research is the social phenomenon being investigated from the participant's viewpoint*". Due to the natural settings of the research, qualitative data becomes an effective model for the researcher/s to acquire detailed knowledge by being involved in the actual experience. A phenomenological study e.g., an interview, one of five types of qualitative studies, will be conducted to gain information of participants perceptions of provided questions (Williams, 2007). The interviews will be carried out with different departments e.g., Logistics, Manufacturing, R&D, Software etc. Table 3 illustrates suitable candidates to interview.

Table 3: *Interviewee information*

Candidate	**Position**	**Current role and past experience**
Interview 1	Safe vehicle engineering	System architect for 8 years (11 years of total experience in the area)
Interview 2	Supply chain outbound logistics	Supervisor for 6 years (17 years of total experience in the area)
Interview 3	Active safety	Principal engineer for 15 years (15 years of total experience in the area)

Interview 4	Supply chain outbound logistics	Yard manager for 1 year (7 years of experience in the area)
Interview 5	Safe vehicle automation radar group	Technical expert in radars for 8 years (24 years of experience in the area)
Interview 6	Safe vehicle automation	Lead architect for 1.5 years (15 years of experience in the area)
Interview 7	Cyber security	Chief product officer for 2.5 years (12 years of experience in the area)

2.3.3 Data triangulation

Triangulation is a technique to measure the validity of a social science research, in this context, a case study (Mertens & Hesse-Biber, 2012). There are several methods of data triangulation, such as investigator triangulation, theory triangulation or methodological triangulation. The method most suitable for this case study is the methodological triangulation due to the nature of it consisting of two subtypes which are within-method and between-method (Wilson, 2014). These subtypes reflect both qualitative- and quantitative research, however only the qualitative data will be used in this project. The qualitative research includes data collection methods such as observations or open-ended interviews (Bekhet & Zauszniewski, 2012). The reason for why methodological triangulation is used is because it has been acknowledged to be beneficial when providing assurance of findings, increased validity, more comprehensive data and enhanced understanding of the subject. By using triangulation in a study, the researchers can increase the strength of an individual method and thus resulting in strengthening the outcome of the study as well.

2.3.4 Workshop

The use of workshops is to gather people with different backgrounds, expertise and experience to get reliable information (Chadwick, 2008). It is also stated that when there is a group of six to eight participants that does not know each other they tend to share more information between each other due to being unsure of the participants’ knowledge (Hennink et al., 2011). For the group to function there needs to be a moderator to keep guiding and keeping the participants active. However, the moderator should not engage in any of the discussions to avoid influencing the group (Chadwick, 2008). The method for the workshops that has been chosen is vernissage where it supports having open and relaxed discussions. This allows the participants to walk around with the sheet of information they have to try and discuss it with other participants which gives room for the moderator to tune in and listen to different thoughts and discussions. Another advantage with this session is that the moderator can ask the participants to give examples, this allows for both better discussions and ideas to be shared, lastly the vernissage session should be around 10 minutes (Mattsson et al., 2009).

The supervisor at Volvo assisted the researchers with creating a group for the workshop, where the researchers were the moderators. The workshops will be conducted during the data collection phase, it will give the researchers an insight on where the company stands and if there is any missed information during the literature review phase. It is believed that the workshops would be beneficial not only for the researchers but also practitioners within Volvo since creating a workshop helps bring people together meaning they could discuss challenges between each other as well. Having the luxury of tuning into the conversation could help support the claims the researchers will make while conducting the thesis.

2.3.5 Data Analysis

Regarding the qualitative data, it is regarded as the identification of categories in data (Hilal & Alabri, 2013). In addition, coupled with observations and a literature study, a data triangulation is going to be carried out. The interviews will be transcribed, and the most relevant data will be selected to highlight and facilitate the research. The data triangulation and researched methods for AT, will evaluate the most suitable solution based on Volvos requirements and the feasibility. After this phase it is believed to compare the results of the interviews, workshop and the theory chapter, to find a middle ground for the most optimal solution regarding AT in manufacturing plants.

This research combines both theoretical and empirical elements, utilizing abductive reasoning as its theoretical foundation. Abduction involves utilizing both deduction and induction as logical reasoning methods (Eriksson & Wiedershiem-Paul, 2014). Deduction involves starting with a hypothesis, in this case an idea about only using onboard sensing and then finding supporting data, such as theories or observations. Induction, on the other hand, involves forming a hypothesis from theories and observations, also known as Grounded theory (Glaser & Strauss, 1967). By utilizing both methods, this study allows for the ability to move back and forth between theories and observations and hypotheses (Eriksson & Wiedershiem-Paul, 2014).

The qualitative data will provide the researchers with both practical and theoretical knowledge of the production in the Torslanda plant and the vehicles AD technology. In addition, with help of observations, the researchers can assure what’s feasible to implement in the parking yard and what technologies that can be used. To further ensure the validity of the AT feasibility, the literature study will be used as a complementary knowledge and guiding tool. Furthermore, by triangulating different data sources, conclusions are drawn by drawing parallels between the different data sets. This will entail that inaccurate or vague information can be sieved out. e.g., mismatch of information with an interviewee and the literature study, or/and other interviewees. This reduces inaccurate information from influencing the practical feasibility of AT.

Lastly, all data is to be illustrated, put into tables, and simply summarized simultaneously as the project proceeds. This results in the data compiling becoming easier thus not needing to be seen as a part of a specific process but instead the whole picture. Figure 5 illustrates the approach of execution.

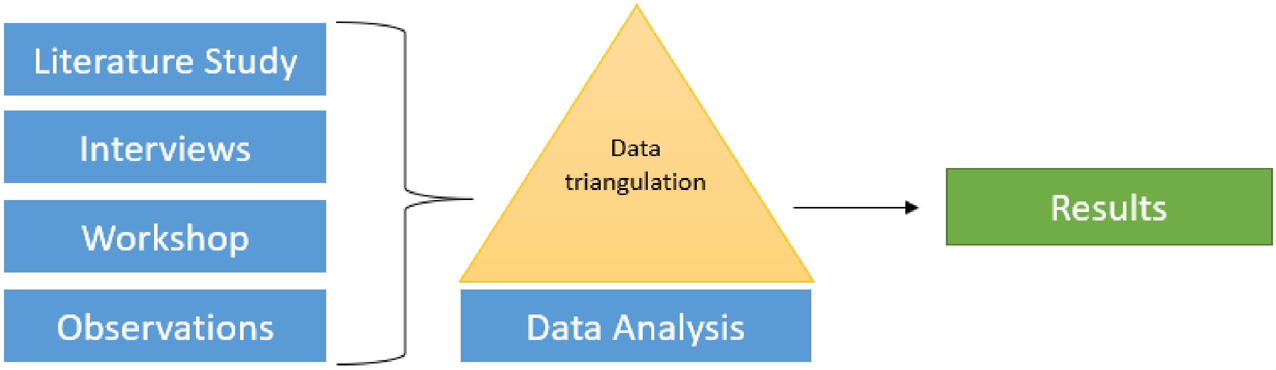


Figure 5: *Approach of execution*

2.4 Ethical Considerations

Harm, informed consent and anonymity/privacy is mentioned as crucial ethical considerations (Bell et al., 2019). To make sure that these parameters are followed several actions have to be taken. Firstly, the interviewees must be informed of how the results of the interviews are going to be handled, used and what the purpose of the study is. This is critical due to it giving the option of the interviewee to participate or not. Moreover, to make sure that no harm comes to the participants being career, mental or self-esteem connected it was concluded that they must be kept anonymous in case of inaccurate information disclosure. The interviewees are planned to be treated with confidentiality thus their real names will not be disclosed and excluded from the study. Lastly, per recommendation of Bell et al. (2019) the group should be in these frameworks to avoid any infliction of unintentional consequence to the participants.

2.5 Validity and Reliability

Quality of a research design is achieved through logical tests and statements (Yin, 2018). The four widely known for their purpose of verifying empirical social research is, construct validity, internal validity, external validity and reliability which will further be discussed in chapter 5, discussion. Furthermore, the author mentions that case studies can be perceived as social research and consequently, the different types of validity would be fitting to use for this thesis. Yin (2018) also argues for the importance of using the logical tests throughout the project, and not only the design phase. Furthermore, how well a sample of a study represents the company is dependent on the representativeness of the sampling frame, which is the part of the company that is accessible for the study. Choosing a sampling frame as a researcher, limits the validity of your study within a specific company, since it is impractical to develop a list for all humans, and equally challenging to create a list for the individuals you wish to generalize to. Thus, the decision regarding the sampling frame must be discussed in the research report (Fowler, 2009).

Random sampling is difficult and ethically challenging, and as a result, many communication research studies do not rely on it (McEwan, 2020). However, sample parameters that do not reflect population parameters can introduce bias in a study design. Selection biases occur when sample characteristics do not represent the population on relevant variables or statistics, and when individuals who are systematically different from those not in the sample are included. Although random sampling can help researchers avoid selection biases, it is not a complete solution to this problem. See Figure 6 for illustrative explanation.

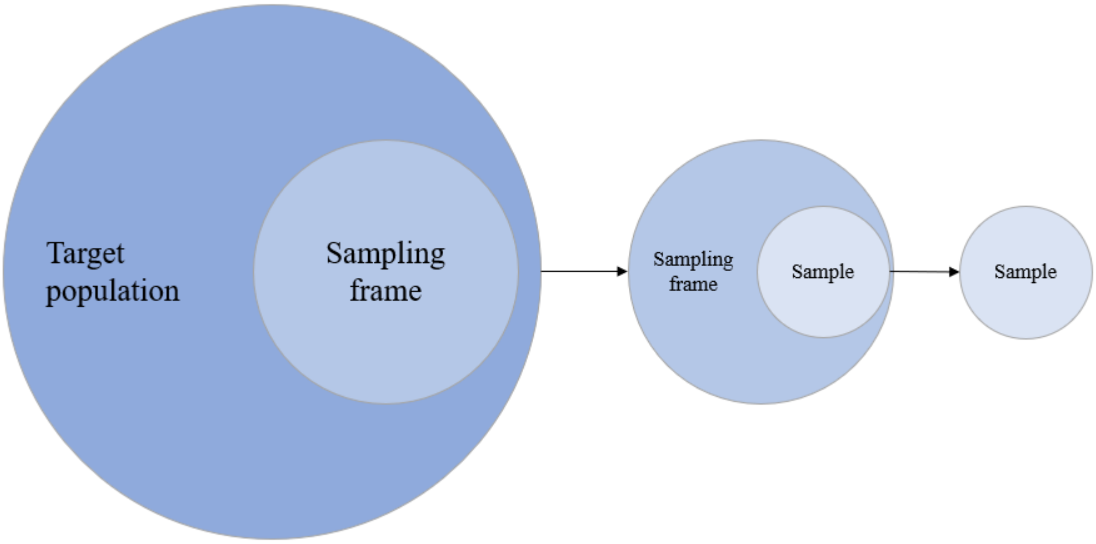


Figure 6: *Visual representation of sampling*

3 Theoretical framework

The following chapter presents the theoretical framework of the thesis. A literature study is performed to find relevant theoretical definitions and perspectives of areas in this project related to autonomous driving technology and infrastructure communication, and an overview of suitable technology to use for guiding and navigating autonomous vehicles. Firstly, an overview of a general vehicle production with the outbound logistics will also be showcased to provide an understanding of the case study. Thereafter, a basic understanding of ADAS and each sensing technology will be presented together. This is due to the perception and planning of autonomous vehicles are the foundation of AD consisting of either a combination of radar, camera, lidar and sensor technology or all together. In addition, infrastructure systems, e.g. UWB and Wi-Fi, with the purpose of communicating and guiding the vehicle together with a localization and mapping system (SLAM) will also be presented. For justification, the GPS in the Volvo vehicle is disabled while it is still in the premises of Volvo's yard. Hence, articles on vehicle navigation and positioning will regard studies conducted indoor since it addresses vehicle's GPS system being unavailable. Lastly, general challenges of AVs and related work to AT solutions in outbound logistics are provided. The overview of the different technologies and the understanding of the production will be the prerequisites for possible solutions.

3.1 Vehicle production

Car vehicle production starts with a customer making an order which contains specific requirements that the car manufacturing company must cope with (Gann, 1996). These specifications are i.e., color, interior- and exterior changes and features. Thus, a large variety of products (cars) can be built in the same factory throughout the day. The car production facilities often consist of the same elements which the car goes through different processes to acquire the customer requirement. They are performed in the following order, stamping, joining, painting, assembling and testing (Omar et al., 2011). The car starts off in the stamping also known as the pressing process where metal sheets are cut and stamped. The big stamping dies are used to shape the metal sheets for the vehicle's chassis, roofs and doors (Monden, 2011). This production area is referred to as the body shop (Volvo source, personal communication, 2023). In the next production area joining occurs where the metal sheets are joined together with the assistance of a robot or manually done by operators. There are multiple different techniques when joining metals together such as laser welding, folding and resistance sealing etc. (Gourd, 1986). Thereafter, the car leaves the body shop and goes into the paint shop where it is treated with anti-corrosion protection. The thin layer of protection is achieved by immersion and applied on the chassis to reduce noise, protect the surface and seal it. This procedure is done by machines to even out the protection (Akafuah et al., 2016). The next and last step in the paint shop is to paint the cars according to customer choice and send them to the next process which is the assembly shop.

The assembly shop is the production area where the cars are built piece by piece in their respective assembly lines. The assembly process is performed mainly by operators instead of machines. The cars move at a certain speed for the operators to follow while walking, this makes it efficient while using manipulators and fixtures to help with accuracy before adding the correct fastening force (Omar et al., 2011). Ensuring that the car is in good quality there are tests done between the procedures. At the end of the assembly the vehicles are tested for the last time and labeled as factory complete before delivered to the end customer. This is commonly called the EOL area.

Toyota's production system has had a large impact on today's automotive industry through the Lean philosophy (Liker & Meier, 2006). Liker & Meier states that the Lean philosophy started in the automotive industry but nowadays can be applied in every production setting. Lean production consists of philosophies such as continuous flow, distribute workload evenly between operators and using a pull system to eliminate waste in products/processes. The flow is built in a way to reduce idle times between assembly stations, this further results in detecting problems quicker down the line since operators can visually see what the station before them has done.

3.1.1 Outbound automotive logistics – EOL stages

Outbound logistics (OBL), commonly known as the automotive logistic chain in the organizational unit that takes place after the car has been produced and is labeled as FC from the production plant. The cars parked in Stage 1 are thereafter being transported manually by a set of operators. Figure 7 illustrates the Stage 1 area in the OBL which is the *handover location drop plan* marked in yellow. The cars are thereafter transported to a parking area which other traffic such as pedestrians or vehicles has crossing routes with. In the parking area the cars are parked at specific slots with the motive of preparation for long haul transportation. These transportations methods are long haul road, sea and rail and local car retailer (Hjalmarsson-Jordanius et al., 2018). The purpose of this procedure is to minimize the transport distance and excluding the need of transporting the operators by a vehicle. This allows vehicles to be pushed out at the rate of the production without any delays (Volvo Source, personal communication, 2023).

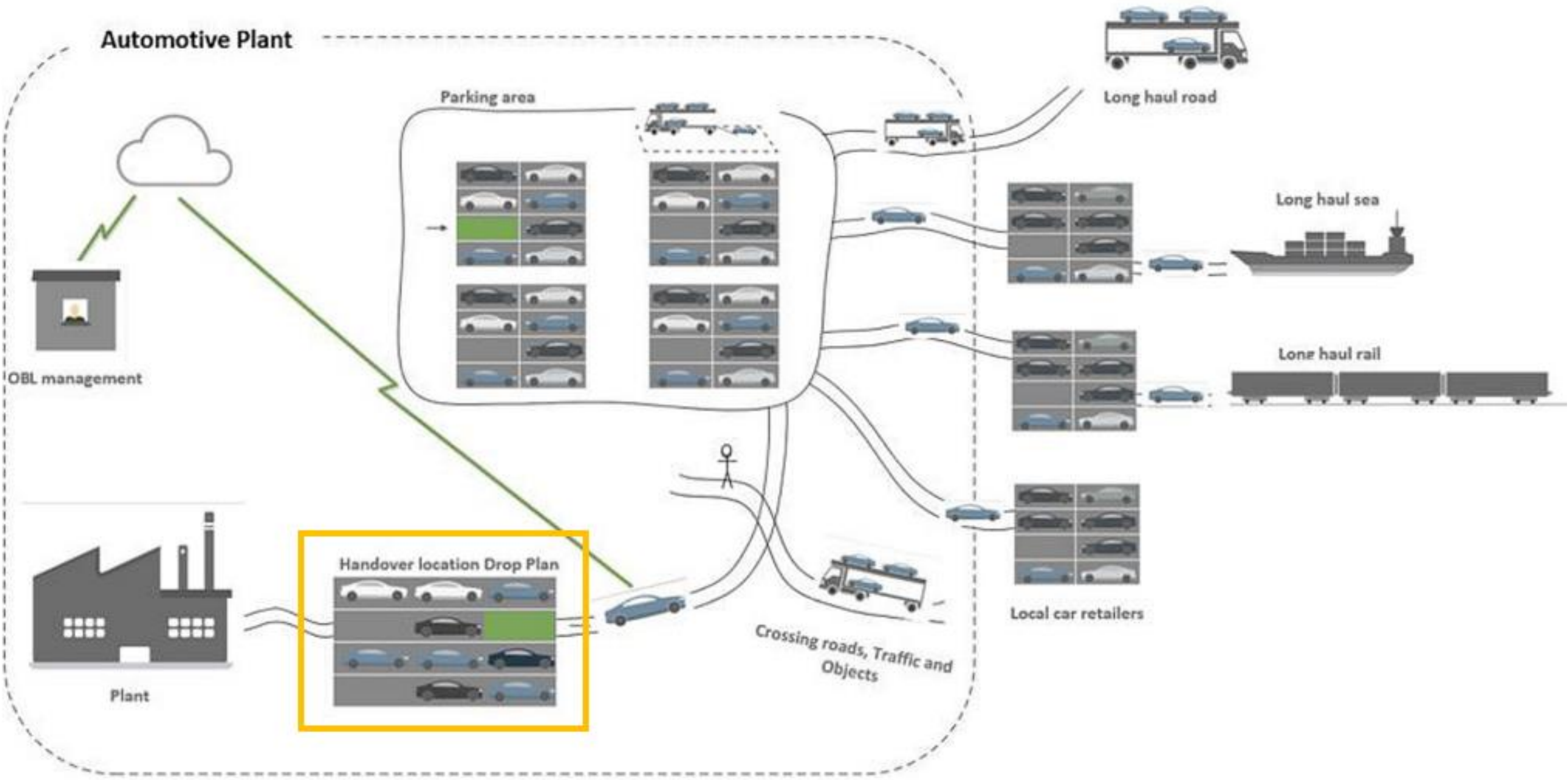


Figure 7*: Outbound automotive logistics (Hjalmarsson-Jordanius et al., 2018)*

3.2 Advanced driver assistant system

The currently technology used in various of automated vehicles of level one or two is defined as an Advanced driver assistant system (ADAS). ADAS technologies are a collection of electronic, light-based, or sound-based systems, illustrated in Figure 8, that have been integrated to create advanced driver assistance systems. These systems' objective is to automate, facilitate, and improve various functions in vehicles to assist drivers in achieving better and safer driving experiences. Moreover, AVs have a 360-degree view of their surrounding environment, enabling them to monitor obstacles and other vehicles on the road. The safety application includes various assistive functions such as adaptive cruise control, lane assistance, emergency assistance, and light assistance (Antony & Whenish, 2021).

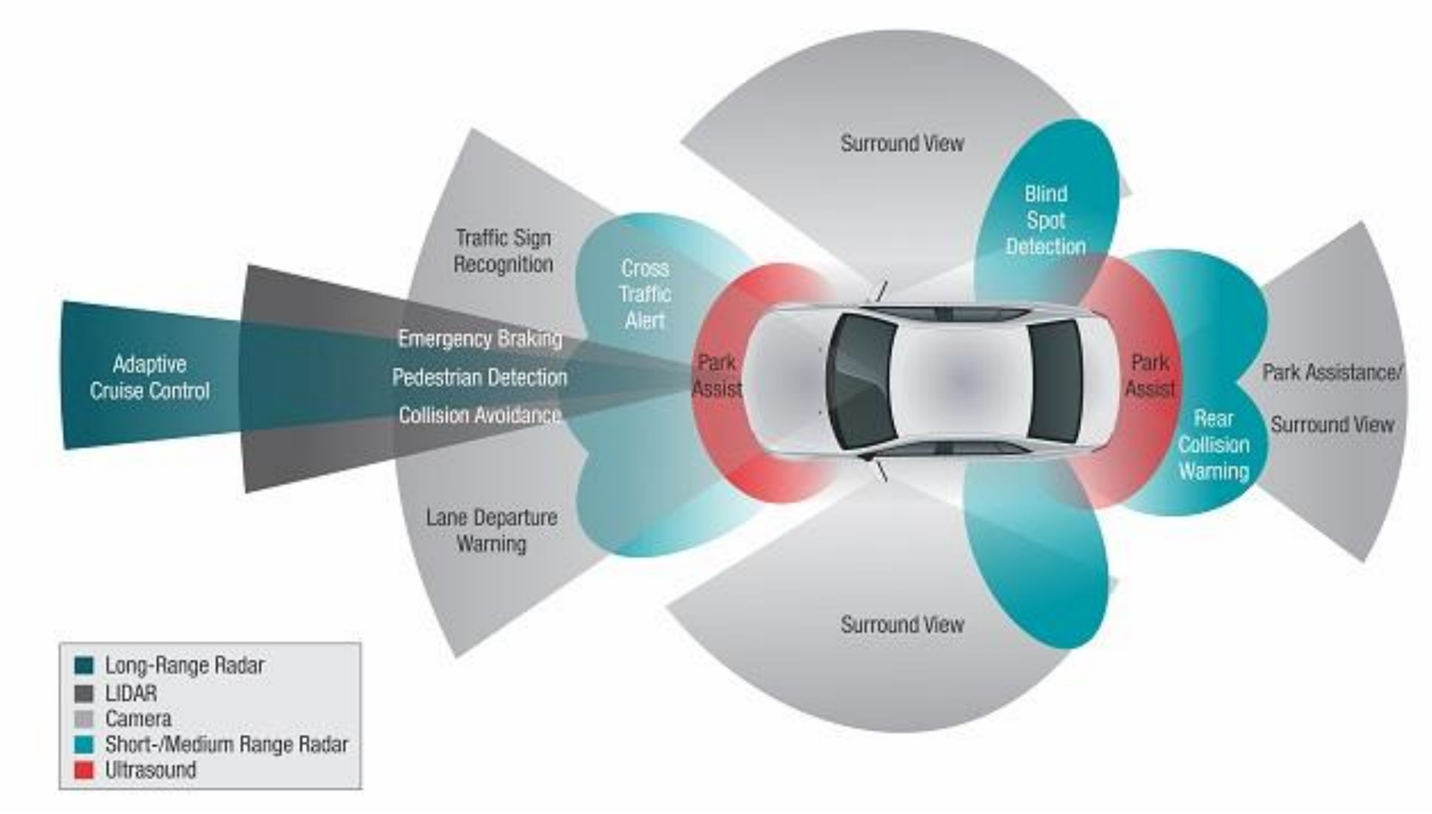


Figure 8*: Features of ADAS technology (Antony & Whenish, 2021).*

Each sensing technology provide specific features. The lane management application utilizes cameras mounted behind the rear-view mirror to monitor road lane markings and detect any drifting outside the lane. Adaptive cruise control applications use radar, speed, and distance sensors to regulate vehicle speed and maintain a constant distance from the object in front. While an array of cameras captures real-time images, it requires heavy graphic processing and high-resolution pictures. Overcoming this challenge has been addressed by fixing a lidar on the vehicle roof to provide 3D visualization of the environment, reducing collisions, and detecting obstacles and other objects. Radars mounted in the front and rear bumpers of AVs are useful in applications such as parking control, lane changing, and bumper-to-bumper traffic (traffic jams). The Inertial Measurement Unit (IMU), an electronic device that collect data for navigation, guidance and control purposes, predicts risk factors that cause hazards. Radar and laser sensors monitor the road and prevent collisions by directing the control to apply brakes and adjust the throttle automatically when something is detected near the vehicle. The blind spot detection application uses radar to detect blind spots and alert the driver. The collision warning system uses position and speed sensors to predict vehicle collisions and sends a warning signal in advance. These environmental factors are interpreted accordingly to a sense, plan and act principle illustrated in Figure 9. Data fusion techniques and intelligent algorithms are applied to further enhance these applications, enabling fast responses and quick decision-making during disaster times (Antony & Whenish, 2021; Kathiresh & Neelaveni, 2021). Functions of each sensor is presented in Table 4.

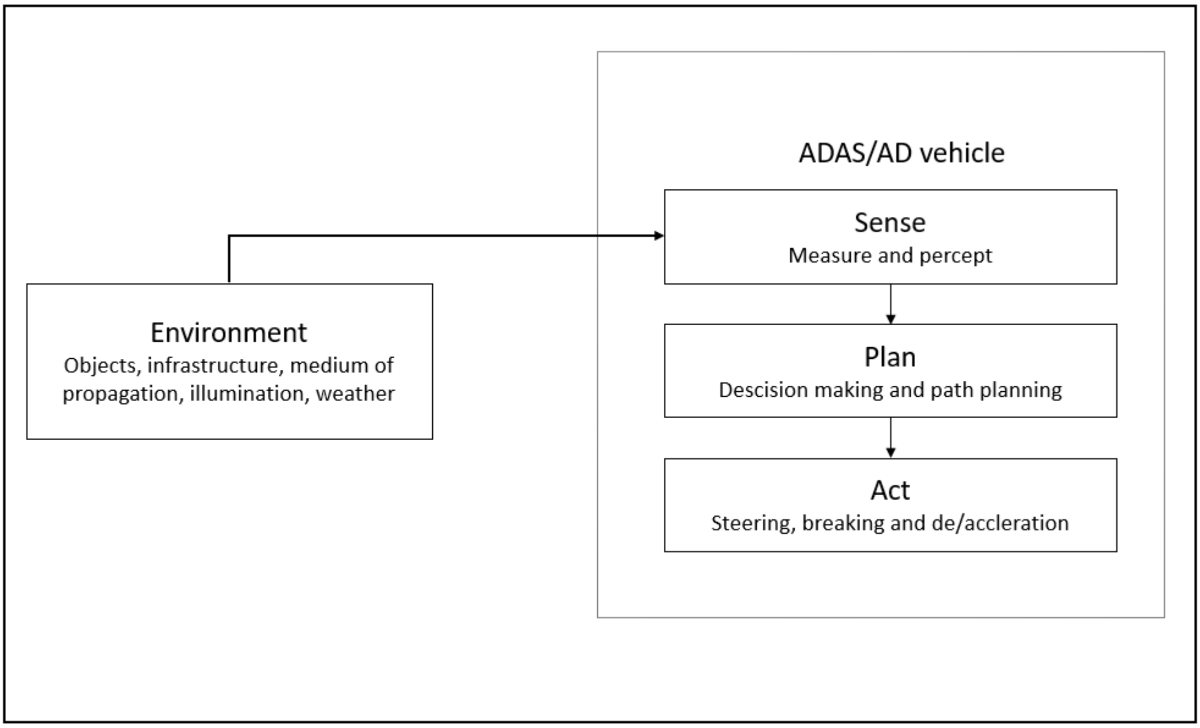


Figure 9*: Simplified illustration of the sense, plan and act model of the ADAS system. Adapted from Schlager et al (2020)*

Table 4*: Various of sensors used with typical application (Antony & Whenish, 2021)*

Sensors	Maximum range (m)	Typical applications
Long-range radar	150	ACC (adaptive cruise control)
Lidar	120	Emergency braking, collision avoidance systems
Camera	80	Pedestrian detection, sign recognition, parking assistance, lane departure warning
Short-range radar	20	Blind spot detection
Ultrasound	3	Park assistance

However, the system's ability to perceive the environment depends on the sensing technology of the vehicle, e.g. radar, camera, lidar, to collect comprehensive data and accurately identify relevant objects. In addition, the vehicles perception comprises two primary functions: simultaneous localization and mapping (SLAM), which produces a map of the environment while concurrently establishing the vehicle's position on the map using sensor data (Chaves-garica & Aycard, 2016). The IMU estimates the vehicle's velocity and orientation and combines with global positioning systems (GPS) to determine the vehicle's current position. However, GPS signals may be disrupted by tunnels, tall buildings, and other obstacles, which is why IMUs sensors provide rotational and linear motion data for the vehicle. GPS also uses cameras, radar and lasers to assess environmental conditions. Radars detect road conditions like snowfall and rain, while lasers fixed on the vehicle's roof provide a 3D view of the surroundings (Kathiresh & Neelaveni, 2021).

3.3 Sensor systems

The following sub-chapter contains different sensor systems. The presented systems primarily cover the sensors that ADAS vehicle currently utilize.

3.3.1 Radar & camera

Radar sensors are getting more topical for every passing day, they are often used in conjunction with traditional sensors such as cameras, infrared, and ultrasonic technology (Bhattacharya & Vaughan, 2020). Unlike these sensors, radar technology can operate in environments without illumination and can be made small and affordable due to advances in integrated circuits. These short-range radars operate at frequencies ranging from a few GHz to hundreds of GHz, making them ideal for collision avoidance in cars and adaptive control of autonomous vehicles, among many other new applications. Figure 10 illustrates the relative strength of GHz frequencies in relation to the metric system. The authors also state that radars provide remote monitoring without the need of a camera thus not infringing on privacy.

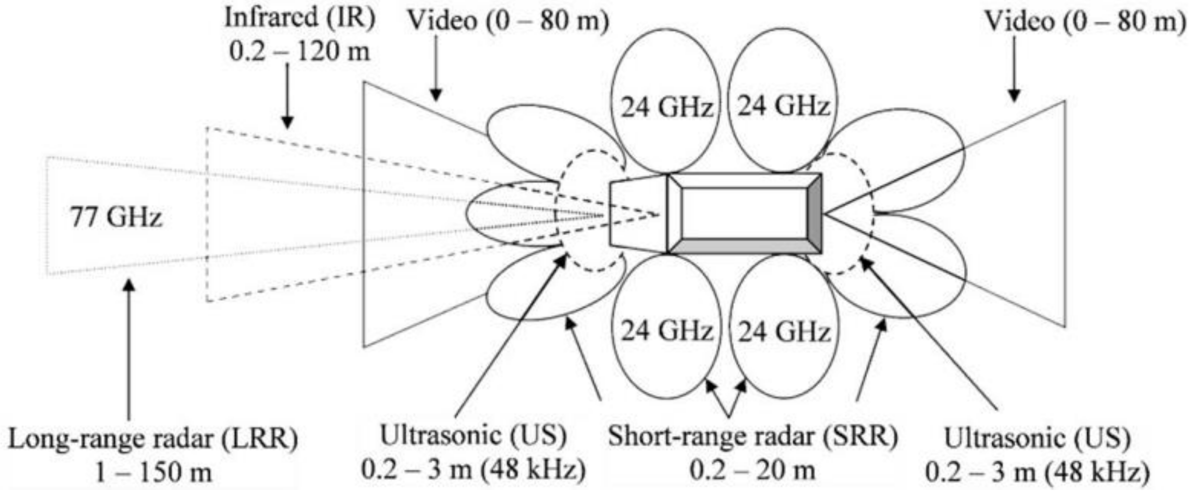


Figure 10: Radar and camera sensors (Ziebinski, et al., 2017)

The success of automotive radar can largely be attributed to its unique physical principle, which offers exceptional performance features at reasonable costs (Dickmann et al., 2016). One of its key advantages is its independence from environmental conditions such as light and weather. Additionally, it can directly measure parameters in space and Doppler velocity, i.e. the velocity vector of an object undergoing scattering as detected by a distant sensor, has multiple fields of view capability, and is easily integrated into vehicle design. Unlike other sensor types, radar can operate under difficult conditions and can even "see" through vehicles using the transvision effect, which exploits reflections between the road surface and vehicle floor to make the invisible visible. As technology has advanced, the performance requirements for automotive radar have steadily increased. From simple detector and ranging tasks in blind spot monitoring or cruise control systems, radars is now capable of smart environment perception tasks for semi-autonomous evasion and braking functions. However, the greatest push in performance requirements has been driven by the trend towards highly automated and driverless driving. Future automotive radar systems must provide imaging-like capabilities and be able to interact in radar networks, allowing for 360 degrees comprehensive perception tasks. In the past, single-sensor concepts were used, but today, multi-sensor networks composed of four or more short-, mid-, and far-range radars are being applied to achieve these goals.

Cameras are one of the first types of sensor systems that were used in vehicles for the purpose of driverless vehicles, this sensor type is currently the main choice for car manufacturers (Kocić et al., 2018). Dozens of cameras are mounted on a novelty vehicle which enables visualization of the surroundings. These cameras are efficient at texture interpretation and more affordable than radar and lidar. However, this comes with a price of needing computational power to process the data. Cameras can produce high-definition pictures with 30 to 60 frames per second, thus meaning multi-megabytes of data will be needed to be processes in real time. Kocić et al., (2018) also states that the application of camera usage for autonomous vehicles are endless and that the application areas are perception, end-to-end autonomous driving, semantic segmentation and many more. A previous study done by Ahmad & Pothuganti (2020) highlights how neural network models such as a convolutional neural system (CNN) can be used to drive cars autonomously. It is a futuristic way of combining artificial intelligence (AI), Internet of things (IoT), blockchain technology, human cloud and robotic techniques. To install this complete system on a vehicle, the camera must be oriented towards the road. The camera's output is then fed into a Raspberry Pi which is a credit-card sized computer, that uses Python (programming language) to facilitate communication between the CNN and other sensors in the network. The Raspberry Pi uploads all the data to a cloud platform, and the vehicle's location can be viewed through a website.

3.3.2 Lidar system

Lidar is a light detection and ranging technology used to scan its environment with laser light being transmitted by a source and reflected to visualize the area in 3D. Due to the laser's superior beam properties and narrow spectra, it has become the preferred source of light. Contrary to e.g. ultrasonic waves, used in parking sensor technology, which suffer large losses in air and limited to a few meters, Lidars range is rather limited to the transmit power (Behroozpour et al, 2017). One or several laser beams are used by a basic lidar used to scan its field of view using a carefully designed beam steering system. The laser beam is pulsed and then reflected to the scanner by the surrounding environment, the received signal is captured by a receptor as shown in Figure 11 (Royo & Ballesta-garica, 2019).

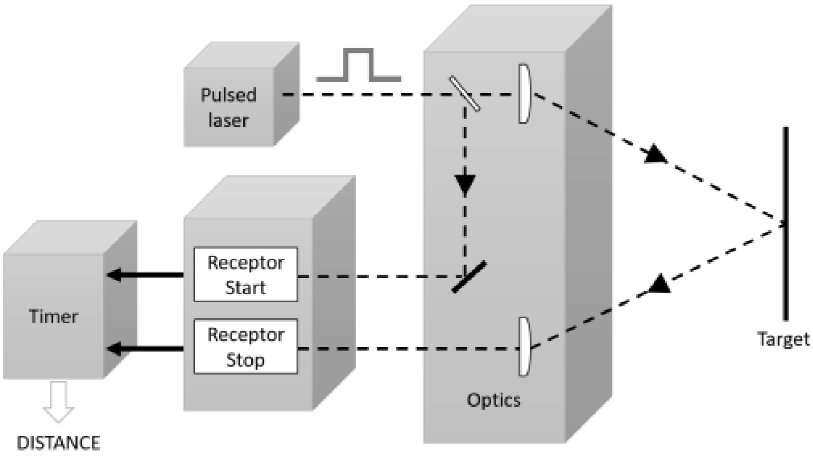


Figure 11*: TOF measurement principle (Royo & Ballesta-garica, 2019)*

By quickly filtering and measuring the time difference between the transmitted and received signals the range is estimated, this is also called time-of-flight (TOF). Furthermore, the variation of reflected energy from the environment provides the lidar system data of the surface materials which enable the lidar to output a 3D map of the scanned environment (Behroozpour et al, 2017; Li & Ibanez-Guzman, 2020).

There are multiple types of lidar systems which have different types of application areas. However, the most common lidar system in ADAS passenger vehicles are the frequency-modulated continuous-wave lidar (FMCW) due to its properties of continuously illuminate objects (Behroozpour et al, 2017). This is a critical function of the lidar, to constantly provide feedback regarding the vehicle's surroundings while operating to avoid hazardous situations. The visualization feedback provided by the lidar is processed by the vehicles. The data processing by the lidar system in autonomous vehicles consist of detection, recognition, tracking and motion prediction (Li & Ibanez-Guzman, 2020). Furthermore, the lidars applications are mainly to avoid collisions e.g. emergency brake assist, lane departure warning and traffic sign assist by detecting objects, such as other vehicles, and estimating distances. It also does provide other functions such as pedestrian recognition and tracking, making the vehicle aware of potential collisions (Zhao et al., 2017). However according to an experiment done by Tang et al (2017), lidar have shown to perform worse in inclement weather conditions, such as heavy rain and snow, in comparison to its full potential i.e. lower probability of detecting obstacles and pedestrians.

3.3.3 Parking sensors

Many contemporary vehicle monitoring systems rely on cameras as their primary detection component, capturing images by recording the light waves reflected by an object's surface (Stiawan et al., 2019). While cameras can produce high-quality images when there is sufficient light, they often perform poorly in low-light conditions or when a medium interferes with the propagation of light such as a different wave coincidently intersecting the same path. Furthermore, this results in the camera providing bad quality images. To address this issue, ultrasonic sensors can be combined with cameras. Ultrasonic sensors leverage the basic principle of sound propagation and reflection by materials in the ultrasonic frequency range, enabling them to operate effectively even in low-light or dark environments. Compared to cameras, the advantages of ultrasonic sensors are that they are i.e. smaller, less expensive, easier to implement, and resulting in less power consumption.

Ultrasonic sensors are widely utilized for various purposes, including determining surface structure, object position, and speed calculation of an object. Ultrasonic sensors emit sound waves from 25 to 50 kHz, see figure 9, to detect objects using the energy reflected onto the sensors (Paidi et al., 2018). To determine an object's shape or structure using ultrasonic sensors, multiple sensors can be arranged in a parallel configuration, and the object can be positioned within their detection area (Stiawan et al., 2019). By gathering data from all sensors that has been recording, the surface structure of the object can be reconstructed. Additionally, the position and velocity of moving objects, such as cars, can be measured by placing ultrasonic sensors at the roadside where the vehicles will pass through. However, the measurement may be disturbed by human or other objects passing through the detection area.

3.3.4 Sensor fusion

Each ADAS technology has its own strengths and weaknesses and can be used for varying purposes and in different settings. While a camera excels in object detection and can obtain detailed information about the detected object, it is limited by its performance in low-light conditions and inclement weather. Moreover, while cameras perform relatively good in high lateral and elevation resolutions, they cannot operate in all conditions. Safety sensors, on the other hand, are designed to function under any circumstance, and therefore, radar and lidar are more effective in such scenarios. These sensors rely on a dependable mechanism for measuring an object's distance and velocity, whereas a camera can only assess distance in a stereo format (Ziebinski et al., 2017).

By sensor fusion, the information collection of the different sensor technologies of the vehicle enhances the autonomous function. Thus, the sensor works in a synergy by supporting each other in terms of complementing their weaknesses with the other sensors’ strength, illustrated in Figure 12. This ensures data to be analyzed and interpreted with a high margin of safety which the vehicle act upon (Ziebinski et al., 2017).

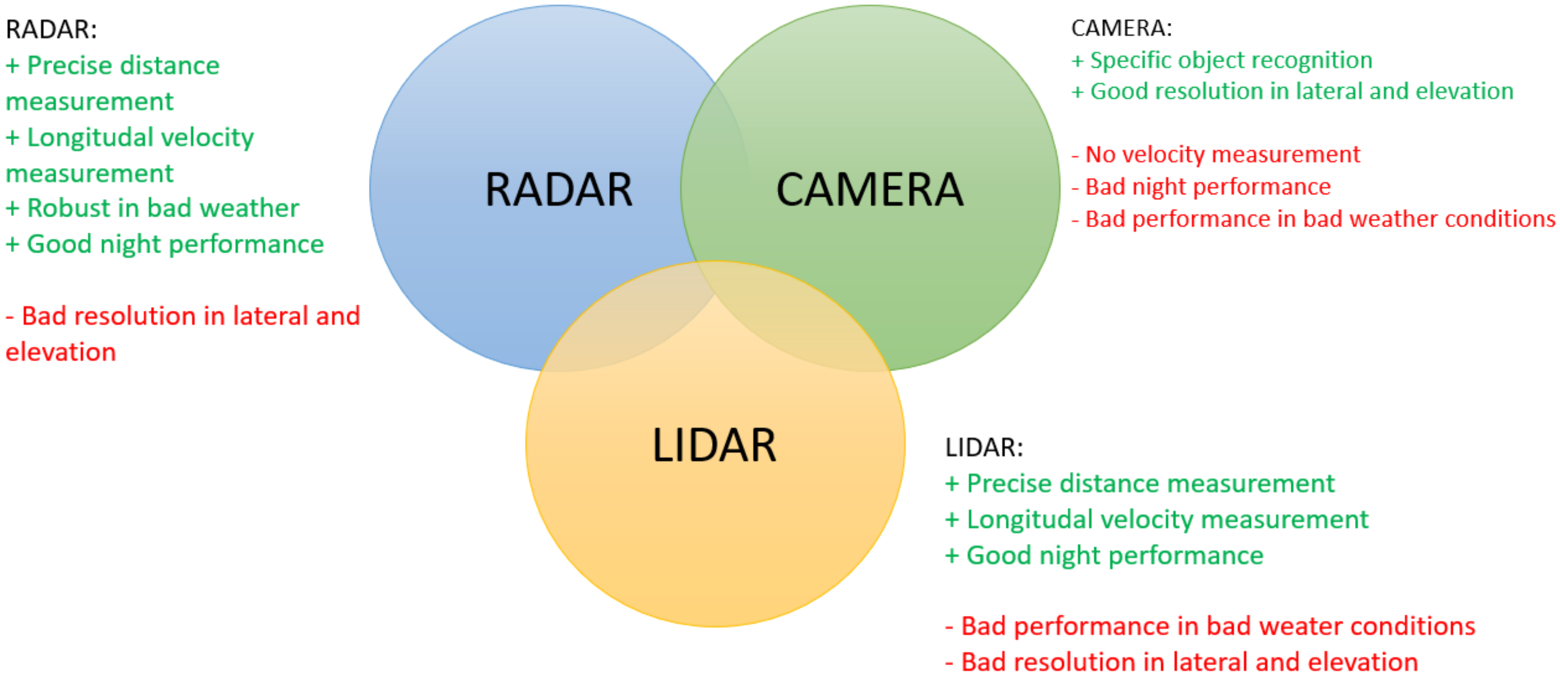


Figure 12*: Technological comparison between the sensors used in ADAS. Influenced by (Ziebinski et al., 2017).*

3.4 Vehicle communication & infrastructure technology

Infrastructure technology defines the external technology, e.g. satellite, traffic systems and other vehicles, which communicates and provides the vehicle with different types of data ranging from weather conditions and localization to emergency avoidance. This chapter describes the vehicle's communication with both the infrastructure and other vehicles. In addition, UWB radio and Wi-Fi, an infrastructure technology partially used to guide vehicles, will also be presented.

3.4.1 Vehicular communications

Vehicle-To-Vehicle (V2V) technology uses a wireless data transmission from one vehicle to another (Arena & Pau, 2019). The communication between the cars primarily aims to hinder accidents of occurring, by enabling vehicles in transit to share data on their position and speed through an ad-hoc mesh network. The technology prominent in the car could alert the vehicle by sending a warning in the event of an accident for the vehicle to take preventative measures independently, i.e., emergency braking. The vehicle's system responds to any dangerous event, which it is being informed by the devices placed on it. The parameters that the devices checks are the distance to an obstacle, travel speed or the presence of another vehicle closing in on the blind spot of the car. However, it is important to note that the technologies used to measure these parameters are increasingly becoming more accurate, calculation errors may occur and should be taken seriously. On the contrary, V2V communication protocols are expected to enhance security performance. By allowing vehicles in close proximity to interact with each other, the technology can assist in resolving issues such as component malfunctions, obstacles in the lane, and other safety concerns, leading to more effective solutions. Nevertheless, the use of Intelligent Transport Systems (ITS) and V2V communications has three main issues that needs to be addressed, the guarantee that the confidentiality and privacy of data sent in multicast and broadcast will be kept safe, the financing of development and distribution of the technology used and lastly, the need for car manufacturing companies to agree with regulations regarding operation and security.

Vehicle-To-Infrastructure (V2I), compared to the V2V model where it allows information exchange between each other, V2I instead enables vehicles to communicate with the surrounding road systems such as, streetlamps, parking meters or traffic lights etc. (Arena & Pau, 2019). An ad-hoc network is used to transmit information between the infrastructure's components and the vehicle in either direction. In the ITS, V2I sensors can detect and obtain infrastructural data and offer information back to the vehicle regarding accidents, available parking spaces or road conditions, all of this occurs in real-time. Thus, also resulting in the management systems being able to utilize the same data to set speed limits and adjust the Signal Phase and Timing (SPaT) to facilitate a smooth traffic flow and save fuel. It is also important to note that, the communication between vehicles and infrastructure which is enabled by the software, hardware and firmware is a fundamental starting point for vehicles driven autonomously.

Vehicle-To-Everything (V2X), The V2V and V2I communication models discussed earlier are encompassed within the more generalized V2X model that can be seen in figure 14, which involves data transfer between a vehicle and any entity capable of affecting it (Arena & Pau, 2019). V2X also includes various specific types of communication such as Vehicle-to-Pedestrian (V2P), Vehicle-to-Roadside (V2R), Vehicle-to-Device (V2D), and Vehicle-to-Grid (V2G). It is important to note that road design flaws and inadequate separation from traffic can significantly impact driver and pedestrian safety. Pedestrian distraction caused by headphones and smartphones, frequently used while walking, is another issue that must be addressed with warning systems. These systems use sensors to calculate relative speed and distance from objects by analyzing differences in time and frequency between sent and received signals. Driving assistance systems such as radars, cameras, and lidar can help address these issues, but they may not be effective in complex scenarios where weak signals are masked by noise or when vehicles are at high speeds or significant distances apart. Finally, the integration and synergy between ITS and technological infrastructure can lead to improvements in transport system performance and the development of innovative applications.

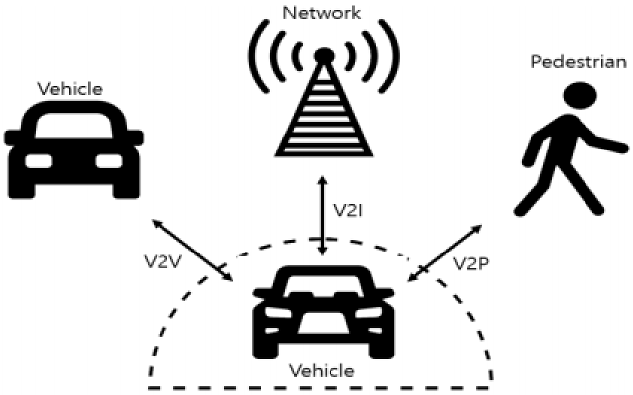


Figure 13*: Data transfer between entities (Kim et al., 2020)*

3.4.2 Ultra-wideband (UWB)

UWB is a radio-based communication technology device in the 3.1 to 10.6 GHz frequency band. This implies that UWB uses short-range and high-bandwidth pulses of radio waves which entails fast and stable transmission of data. UWB can accurately measure the distance between two devices and provide precise positioning and location tracking with a relatively high accuracy, making it useful for a variety of applications such as indoor navigation and asset tracking. This level of accuracy is achieved through the use of high-frequency radio waves that can penetrate solid objects and bounce off surfaces to determine the exact location of a vehicle in real-time. In addition, UWB has the capability to transmit large amounts of data securely and also being resistant to interference from other wireless signals (San Martin et al., 2020; Opperman et al., 2004).

3.4.2.1 UWB application for autonomous vehicles

According to Jiang et al. (2022), due to UWB's low power consumption, resistance to interference, penetration capabilities, and high accuracy in determining location, it has been considered of the key technologies of next-generation wireless communication. According to Minoli & Occhiogrosso (2018) UWB technology is crucial for the development of self-driving cars. One of the major challenges in developing AVs is ensuring accurate positioning and localization. UWB technology can address this challenge by providing a centimeter-level or millimeter accuracy in positioning (depends on the application), which is of a high importance to ensure safe and reliable operation of self-driving cars. Another essential application of UWB technology in autonomous cars is object detection and ranging. UWB sensors are capable of detecting and locating objects with high accuracy, even in challenging environments such as poor lighting or bad weather conditions. This makes UWB sensors ideal for detecting and avoiding obstacles on the road, such as other vehicles, pedestrians, and road hazards (Minoli & Occhiogrosso, 2018). Moreover, UWB technology can improve the accuracy of map data, which is critical for the safe operation of autonomous cars. UWB sensors can be used to create highly detailed maps of the road and surrounding environment, e.g. the location and shape of curbs, buildings, and other structures. This information can be used to create highly accurate and up-to-date maps that are essential for the safe operation of self-driving cars signals (San Martin et al., 2020).

Another potential application of UWB technology in autonomous cars is V2V communication. UWB sensors can enable communication between vehicles, improving safety and efficiency on the road. For instance, cars can use UWB technology to share information about their location, speed, and direction of travel, which can help to avoid collisions and reduce traffic congestion. The UWB technology can also enhance the overall performance and reliability of AVs. UWB sensors can provide highly accurate data on the position and movement of the vehicle, which can be used to optimize the performance of the car's sensors and control systems. This has potential to improve the safety and reliability of AVs (San Martin et al., 2020).

3.4.2.2 UWB beacons for autonomous vehicles

UWB technology has the application to areas where GPS signals are weak or unavailable, such as indoor parking lots or urban enivornments (Jiang et al., 2020). The authors suggest installing UWB beacons at strategic locations in the area where the autonomous vehicle will operate in e.g. inside a parking garage, where an autonomous vehicle can use UWB technology to accurately determine its position and navigate to its destination. In addition, UWB technology is shown to be more suitable for vehicle navigation compared to other positioning technologies such as, Wi-Fi, Bluetooth, Zigbee, RFID etc. due to its properties previously mentioned. However, in relation to other positioning technologies UWB is considered a high investment cost (Brena et al., 2017; Mautz, 2012).

Autonomous vehicles are commonly equipped with UWB receivers which provide the ability to communicate with the UWB (Jiang et al., 2020). UWB receivers use the UWB signals from beacons to precisely determine their location relative to the beacons. This is done by measuring the time it takes for the UWB signal to travel from the beacon to the receiver and using this information to calculate the distance between them. By using multiple beacons which are mounted to a physical object such as a wall or a pole, the receiver can determine its position relative to the beacons with high accuracy (Opperman et al., 2004; Ullah et al., 2009).

Furthermore, UWB beacons can be used to navigate and guide vehicles through a process called UWB positioning. This involves the use of UWB beacons placed in a known location and a receiver on the vehicle to determine its position and guide it along a desired path. The path guidance can be done by e.g. providing feedback through the steering wheel and/or other control systems (Jiang et al., 2020). This implies that UWB technology works together with the vehicle’s sensors such as camera, lidar and radar for high accuracy positioning. In conclusion, the UWB beacons are most suitable for unmapped environments to enhance the vehicles positioning in combination with its own sensor technology (Martin et al., 2020). Figure 14 illustrates a simplified version of UWB anchors/beacons’ communication with the vehicle.

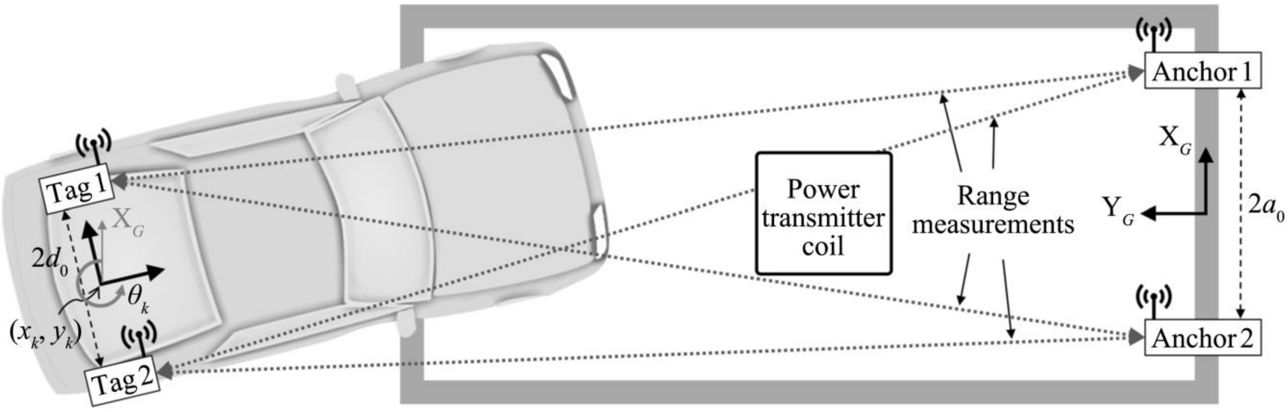


Figure 14: *UWB beacons for vehicle localization and management (Lee S.M, 2021)*

3.4.3 Wi-Fi

Wi-Fi is a wireless networking technology that allows devices to connect to the internet or communicate with each other without using wires or cables. It is designed to provide a local wireless connectivity in e.g. offices, public and workspaces etc. It uses radio waves to transmit data between devices that are equipped with Wi-Fi adapters, e.g. smartphones, laptops, tablets, smart home devices, vehicles etc. Wi-Fi technology relies on a wireless router or access point to provide a wireless network connection, which is usually connected to a wired broadband internet connection. (Al-Alawi, 2006).

3.4.4 Wi-Fi application for autonomous vehicles

Wi-Fi has the ability to provide high speed data for indoor applications (Kaushik, 2012). One application is localization and navigation in autonomous vehicles through Wi-Fi, which can enable a vehicle to navigate through an indoor space such as a warehouse, factory, or parking garage. This technique is mainly used due to the GPS signals in vehicles being weak or unavailable. One technique used for navigation is called *Wi-Fi fingerprint localization*, used for indoor positioning and navigation by creating a map based on the Wi-Fi's signal strength. It also use these measurements to determine the location of a device/vehicle with a Wi-Fi receiver (Dinh-Van et al., 2017. Furthermore, by fusing complementary technologies of the vehicles, e.g. camera, a 3D map can be synthesized, improving the accuracy of the localization and navigation (Liu et al., 2020).

According to by Nguyen et al. (2016), it is not recommended to solely use Wi-Fi for localization and navigation. The accuracy of Wi-Fi fingerprint localization can be affected by multiple factors e.g. signal interference, changes in the indoor environment, and variations in device hardware and software (Nguyen et al., 2016). Thus, by using complementary devices such as UWB beacons improves the accuracy and reliability of indoor navigation (Monica & Bergenti, 2019). Another issue is low sampling rate, implying that a standard 2.4 GHz, in comparison to UWB with at least 3,1 GHz, Wi-Fi receiver take on average 0,9 seconds to complete a scan of a Wi-Fi signal. The issues arise regarding to safety where the low sampling rate has the capability to react to average human speed (3-5 km/h). Thus, if the vehicle needs to react to a speed above 3-5 km/h, a complementary technology is recommended or a more advanced Wi-Fi technology (Nguyen et al., 2016). However, Wi-Fi fingerprint localization is considered a relatively low-cost and scalable method of indoor positioning since it does not require additional hardware or infrastructure beyond existing Wi-Fi networks (So et al., 2013). This implies that if a more advanced Wi-Fi technology beyond the standard 2.4 GHz is required, it might not be defined as low cost and scalable (Nguyen et al., 2016; So et al., 2013).

3.4.5 Hybrid localization using Wi-Fi and UWB beacons

According to a study done be Monica & Bergenti (2019), combing the UWB and Wi-Fi technology provides a more robust and accurate localization. The authors stated that Wi-Fi provide a coarsed-grained positioning information while UWB provide fine-grained. These technologies can work as complementary technologies to enhance the accuracy and robustness of the localization system, e.g., making the vehicle capable of operating in a wide range of environmental conditions. Another study done by Caso et al. (2018) concluded that UWB beacons had an overall better performance than Wi-Fi. However, the authors tested the combination of UWB and Wi-Fi which resulted in a higher accuracy and better robustness. Furthermore, Zhuang et al. (2016) states, contrary to UWB which require dedicated infrastructure and beacon devices to detect signals for positioning, Wi-Fi is chosen due its already existing availability, resulting in a relatively low infrastructure investment and no additional hardware investments. Furthermore, UWB can be used to provide precise positioning information, while Wi-Fi can be used to provide additional context information about the environment (Martin et al., 2020; Monica & Bergenti, 2019). While Wi-Fi's accuracy is influenced by shadows and reflections, UWB works in a complementary function to validate and/or rectify the position information (Monica & Bergenti, 2019).

3.5 Simultaneous localization and mapping

SLAM stands for Simultaneous Localization and Mapping. It refers to a technique used in robotics and computer vision to build a map of an unknown environment while simultaneously keeping track of the robot's position within that environment. SLAM algorithms use sensor data, such as laser rangefinders or cameras, to detect and locate. The detection generates an online 3D mapping that appears to be the starting point in navigation of the 3D world with complete autonomy (Debeunne & Vivet, 2020). A 3D map includes plain geometric features such as circles, curves or lines but also complex semantic objects such as humans, buildings or cars. The consistency of a map will result in the robot detecting obstacles, free spaces and landmarks more easily with the purpose of navigating safely and precisely. At the same time, the algorithm uses the robot's movements and the sensor data to estimate the robot's location and orientation within the map.

Furthermore, that kind of a map can be used by a human operator to get a preview of the environment to then put up a pre-defined path that the robot will follow. The robot itself could also use its AI capabilities to carry its own mission out with complete autonomy. Which means that the robot plans its own path to make the correct decisions without human interference. A robot like that maintains stability and plans the movement on its own, to an extent where even if there are unexpected deviations occurring. The main goal of SLAM is to enable a robot to navigate and operate autonomously in unknown environments. SLAM is used in a variety of applications, including autonomous vehicles, drones, and mobile robots (Alsadik & Karam, 2021).

3.5.1 SLAM in autonomous vehicles

SLAM is a vital technology in the development of autonomous vehicles, as it allows the vehicle to understand and navigate the environment it is operating in. According to the research done to SLAM, it can be integrated into autonomous vehicles for *Mapping*, *Localization*, *obstacle detection and avoidance,* and *Dynamic mapping*:

Mapping: SLAM can be used to create a map of the environment that the vehicle is operating in. This map can then be used by the vehicle's autonomous navigation system to plan and execute its movements. The vehicle can communicate the mapped information to other vehicles for them to better orient and plan for themselves (Debeunne & Vivet, 2020).

Localization: SLAM can be used to accurately locate the vehicle within the environment it is operating in. This is done by using sensor data from cameras, lidars, or other sensors to estimate the vehicle's position and orientation relative to the map created using SLAM. Furthermore, localization is required when dispatching multiple vehicles (Gao et al., 2020).

Obstacle detection and avoidance: SLAM can be used to detect obstacles in the vehicle's path and plan a new route to avoid colliding with them, these obstacles can be things such as pedestrians or other vehicles. Furthermore, another reason path planning process is because it decreases complexity and is refined and improved based on the dynamic restrictions. This is done by continuously updating the map and the vehicle's position within it as the vehicle moves through the environment (Ramabalan et al., 2021).

Dynamic mapping: SLAM can be used to dynamically update the map as the environment changes. The dynamic model includes variables such as trajectory tracking to try and reduce upcoming errors. For example, if a new obstacle appears in front of the vehicle the SLAM system can be used to update the map in real-time (Ramabalan et al., 2021).

3.6 Infrastructure enabled autonomy

Infrastructure enabled autonomy (IEA) refers to the use communication and sensing technologies of the vehicle (lidar, radar, camera etc.) embedded in the surrounding infrastructure, such as UWB and/or Wi-Fi to enhance the capabilities of autonomous vehicles in confined areas e.g. parking garages. The objective with IEA is to create a more robust system that improves the safety and reliability of autonomous vehicles (Zhao et al., 2023). The AVs sensing technologies is part of the vehicle's functional architecture, illustrated in Figure 14, representing multiple hardware and software components and the interactions between them. The vehicles hardware consists of sensors, connectivity and actuators which gathers information of the environment. The software processes the data input from the environment and provides the vehicle with a cognitive ability to percept, plan and control the vehicle, which is a continuous process during the vehicle's operation (Kathiresh & Neelaveni, 2021; Kocić et al., 2018).

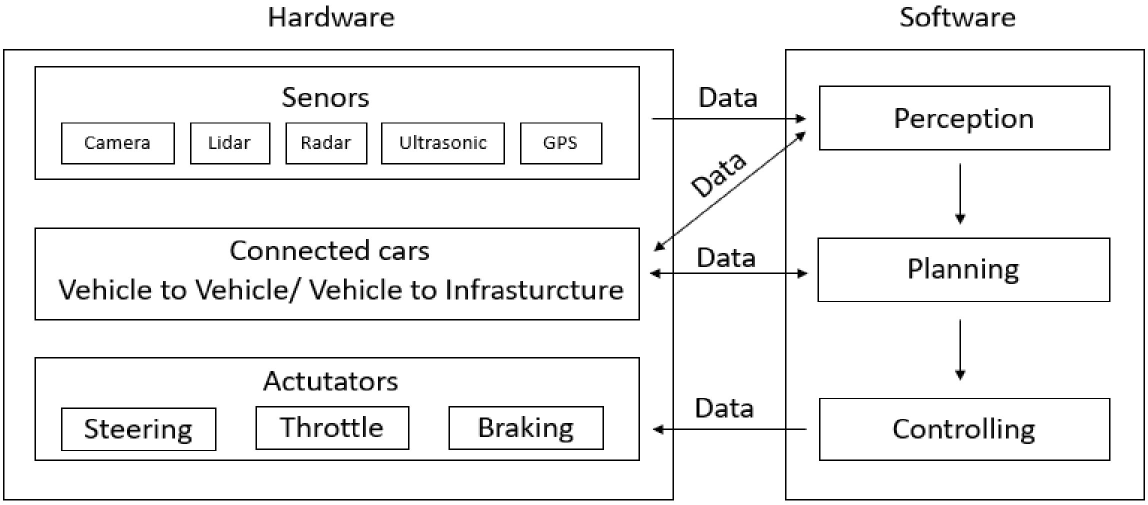


Figure 15: *The functional architecture of an AV. Adapted from Kathiresh & Neelaveni (2021)*

3.7 General challenges in AV

There are many challenges regarding the development of autonomous vehicles. According to Kathiresh & Neelaveni (2021), there are seven defined challenges that entails the development of autonomous vehicles: *Theft of data, theft of vehicle, network risks, high cost, object detection, Deep learning architecture,* and *threats.*

Theft of data: Cyber security is the practice of protecting data from theft, damage or unauthorized access. Today's digital age has critical effects of cyber security because a breach can result in significant damage to reputation and compromise of sensitive data. Due to the vast amount of data generated by in-vehicle sensors through the connected vehicle, there is an increased risk of data theft by hackers who may potentially gain access to personal information, financial details, location data, and entertainment preferences.

Theft of vehicle: In recent times, digital keys, mobile applications, and wireless key fobs have become popular for securing and accessing vehicles. However, there is a potential risk of unauthorized access to these virtual keys by intercepting the communication between a wireless key fob or vehicle.

Network vulnerabilities: In V2V and V2I communication, such as Wi-Fi, cellular networks, and Bluetooth, have made them an easy target for hackers, increasing the risk of service corruption and unauthorized network access.

High cost: High system cost is a concern in object detection, as achieving 360° vision requires integrating multiple devices, generating large amounts of data, and necessitating high-power processors for image analysis. The commercialization of AVs necessitates the adoption of low-cost hardware and communication techniques.

Object detection: Detecting fast-moving objects on the road is a challenge for AVs.

Deep learning architecture: Developing a specialized deep learning architecture for AVs is a crucial task in the automotive industry.

Threats: Unauthorized data manipulation, corruption, device hacking, and counterfeiting are significant threats to AV.

3.8 AT in automotive manufacturing and logistics

A previous study on AT in the logistic industry, including automotive, done by Hjalmarsson-Jordanius et al. (2018) provides an insight into the potential impact of AT on the logistics industry. The authors highlight the benefits of driverless intelligent transportation, such as increased safety, reduced costs, and improved efficiency. However, they also note the challenges of regulatory framework, societal acceptance, and job displacement. As the technology for autonomous transport continues to evolve, it will be essential to address these challenges to ensure the safe and successful adoption of driverless intelligent transportation.

Furthermore, the authors address an AT solution in the outbound logistic domain of the automotive industry and concluded that it will reduce the amount of personnel as well as increasing the storage capacity and safety. By introducing AT it increases the storage capacity since cars can be parked closer to each other without needing space for a driver to enter or exit the car. This can lead to an overall increased production capacity at the factory. Moreover, by eliminating errors made by humans operating the vehicle, the risk of damage occurring may be reduced, and the need for trailers to transport production cars onto ships, trains, or long-haul trailers can be minimized.

The paper provided a general overview of the AT solution, illustrated in Figure 15, by using an off-board traffic control system, an infrastructure communication system, with real-time data working together with the vehicles onboard ADAS sensors through mobile technology connectivity i.e. V2I. According to the authors, this enables up to level 4 of autonomy.

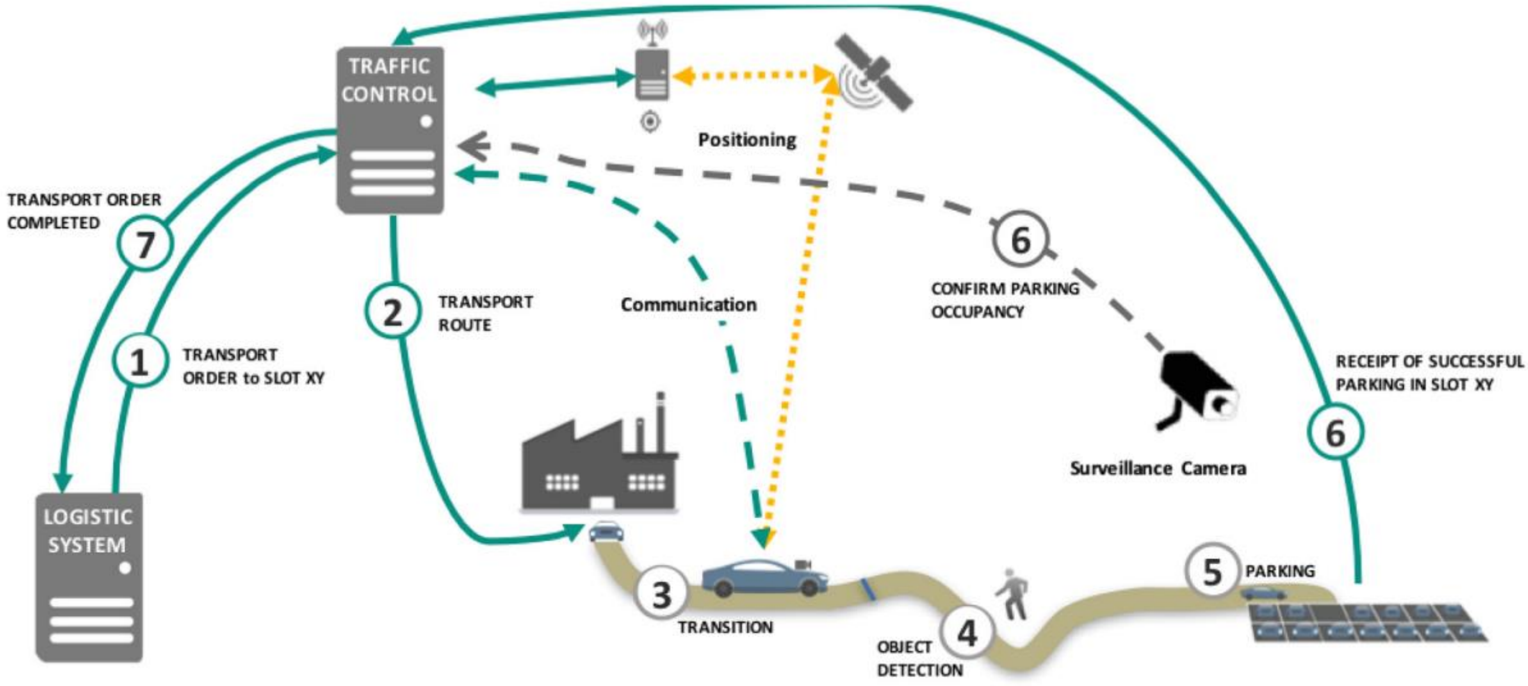
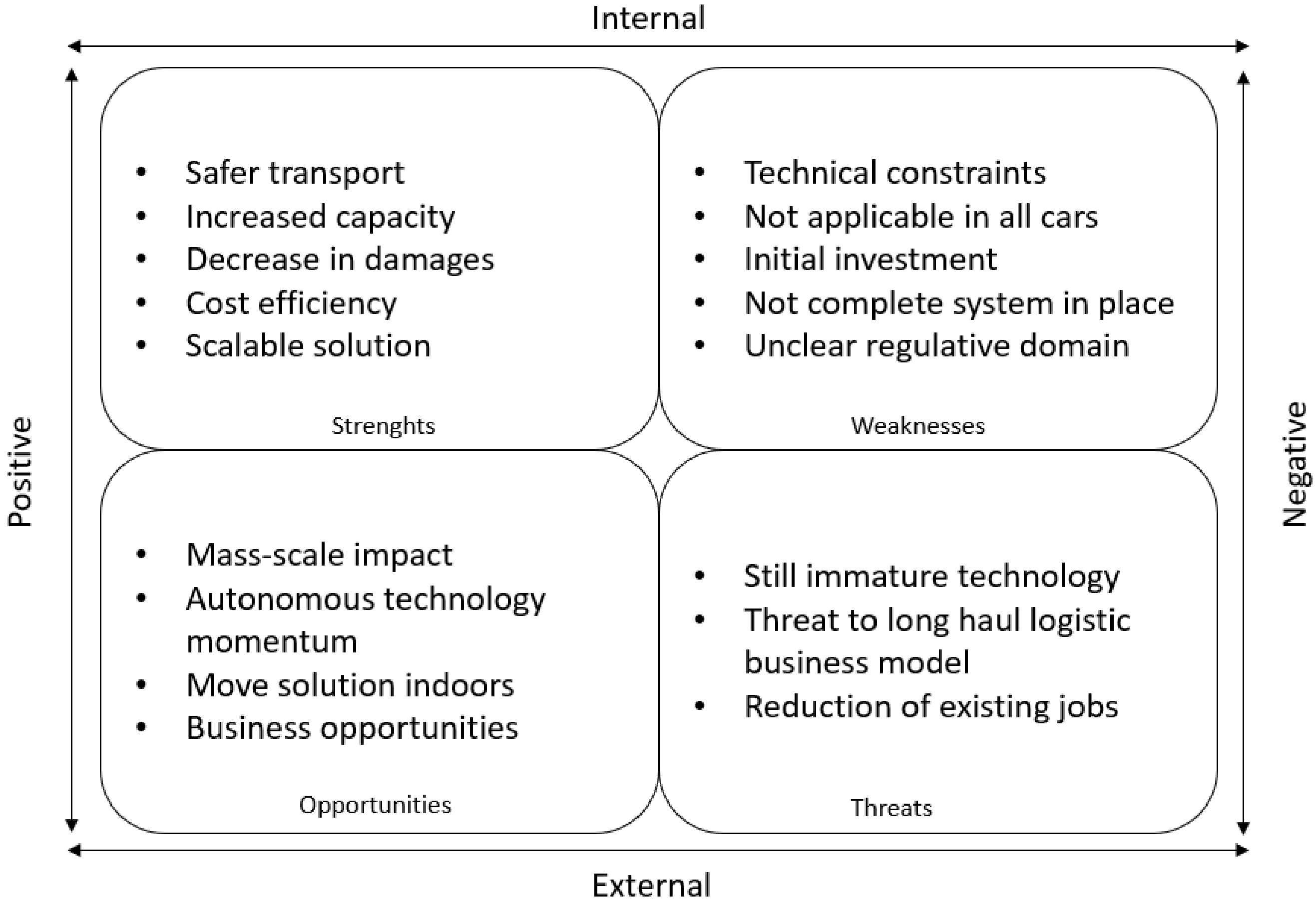


***Figure 16**: Overview of the AT solution (Hjalmarsson-Jordanius et al., 2018).*

Moreover, each driverless FC-car being transported within the logistics flow is managed by an intelligent off-board traffic control system, which directs the cars from point A to point B and manages their interactions with each other. By cross-referencing the FC-cars' sensor data with transport mission data, the FC-cars equipped with the AT solution can calculate their own locations, negotiate routes to their destinations without human intervention, adapt to the speed limits of the OBL yard, and automatically stop if any object or hazard is detected ahead. The utilization of this traffic control system provides flexibility, enabling it to accommodate changes in production processes, reorganization of routes in the OBL yard, or changes in the structure of the parking lot. In addition, the system monitors various parameters such as speed, remaining fuel, electric power level, logistics data, and operational status of each car. The authors also states that if the yard is partitioned into sections, the system operator can easily shut down specific areas of the yard and automatically re-direct the vehicles in the logistics flow to execute individual transport missions.

Furthermore, the authors conducted a SWOT-analysis (Strength, weakness, opportunities and threats) of implementing an AT solution, illustrated in Figure 16. The SWOT-analysis provides the advantages and disadvantages of what an idea can entail. The axle on the strengths and opportunities side are defined as a positive outcome of the idea, while the other axle of weaknesses and threats are perceived as negative. In addition, the internal axel describes the in-house factors that needs to be addressed or considered, while the external axle poses the external factors of e.g. regulations, competitors, social acceptance, and also opportunities of new collaborations etc. Moreover, this shows even though there are a lot of opportunities and benefits to an AT solution, there are multiple factors that need to be addressed. These challenges require further research upon before implementation of an AT, especially on a larger scale where the AVs use public transport to designated destinations.



- Safer transport
- Increased capacity
- Decrease in damages
- Cost efficiency
- Scalable solution

- Technical constraints
- Not applicable in all cars
- Initial investment
- Not complete system in place
- Unclear regulative domain

- Mass-scale impact
- Autonomous technology momentum
- Move solution indoors
- Business opportunities

- Still immature technology
- Threat to long haul logistic business model
- Reduction of existing jobs

Figure 17*: SWOT analysis of an AT solution*

4 Empirical analysis and results

This chapter will present the findings of the empirical study and the results of it. The findings relate to the how AT will affect the yard operation and moreover on AT limitations, solution concepts, investment cost, regulations and cyber security. Table 5 provides the reference nomenclature for the interviewees. The interview finding will be presented in combination with the observations. Thereafter, data triangulation between the empirical findings and the literature will be presented to address the validity of the interview data and the feasibility of an AT implementation in Stage 1. In addition, the alternative solutions and the investment costs of them will be presented based on the outcome from the workshop.

***Table 5**: Nomenclature for interview references*

References	Department	Occupation
A1	Research & Development	Safe vehicle engineering
A2	Research & Development	Active safety
A3	Research & Development	Radar expert
A4	Research & Development	Safe vehicle automation
A5	Outbound logistics	Supervisor
A6	Outbound logistics	Yard manager
A7	Cyber security	Chief product officer

4.1 Solution concepts

This chapter present the alternative solutions of an on-board respective off-board technology. The presented solutions are influenced by the workshop participants' ideas and opinions in combination with the researchers' ideas. The participants of the workshop are presented in Table 6, excluding the researchers. The objective with the workshop was to both validate the interviews findings and to gain more detailed information regarding how respective solution should be constructed and functioning.

Each solution concept is illustrated and presented in further detail in the sub-chapters below. The solutions were constructed by the researchers based on the outcome of the workshop. The concepts provide a general idea of how the solutions should be constructed. Thus, implementation of preferred solution might come with limitations based on the operation, which might require adjustments to the concept. On-board requires more time and additional resources to develop in comparison to off-board which a supplier can provide. Moreover, the vehicle cover was addressed in the workshop which favored the off-board concept. In addition, the off-board was favored in terms of the time for implementation in relation to the on-board due to software development requirements. Further details on the investment cost for the alternatives is presented in chapter 4.4.

***Table 6**: Workshop participants*

Department	**Occupation**	**Expertise**
Engineering and operations	Strategic product manager	AD/ADAS
R&D	Lead solution architect	Safe vehicle automation
R&D	System architect	Safe vehicle engineering
R&D	Technical director	
R&D	Principal engineer	Active safety
R&D	Product engineer	Valet automation parking
Outbound logistics	Outbound logistic engineering	Outbound logistics
Manufacturing engineering	Manufacturing engineer	Software download and final test

4.1.1 On-board concept

Figure 19 illustrates the concept of using on-board sensing for the guidance and localization of the vehicle. The idea is that the vehicle manages the driving itself while being provided with information of its destination and if needed, re-routing. The information flow process consists of a logistic system that provides the traffic control system with coordinates for each specific vehicle that enters the outbound port from the factory, this occurs automatically. Thereafter, the vehicle receives the coordinates and begins to drive towards designated parking spot. In the process of driving the route, the vehicle provides constant feedback communication to the traffic control regarding positioning, speed, fuel and object detection. If an object is detected, the vehicle will stop immediately and update the traffic control of the situation in order to either receive a re-routing order or to stop until further notice. When a vehicle has arrived at the given coordinates, the traffic control updates the logistic system that the process is finished. The concept is based on using the vehicles AD technology which includes all ADAS sensors for accurate localization and mapping of the area and object detection. This allows the vehicle to be in charge of its cognitive function and actuators to navigate itself in the area. In addition, the communication between the logistical and traffic control system and the vehicle is through either Wi-Fi, 4G or 5G, depending on the required performance in bandwidth.

Furthermore, due to the GPS being disabled while the vehicle is in factory mode, a SLAM system was suggested to address the localization and mapping issue. The vehicle will be able to create a 3D map, with the help of all the ADAS sensors, of the environment which can be shared among other vehicles as a pre-defined map. The map can also be updated in real-time, which update other vehicles with changes in the area, including object detection. This allows the traffic control system to provide accurate routing information to vehicles that have not interacted with objects yet, entailing less disruptions to the flow. For clarification, the mapping of the area will be pre-defined by a vehicle first by driving around in the area to identify the localization in order to provide a map. The map is thereafter stored in the traffic control system in order to share it among other vehicles. This allows the vehicles to interpret the coordinates given by the traffic control, before existing the outbound port.

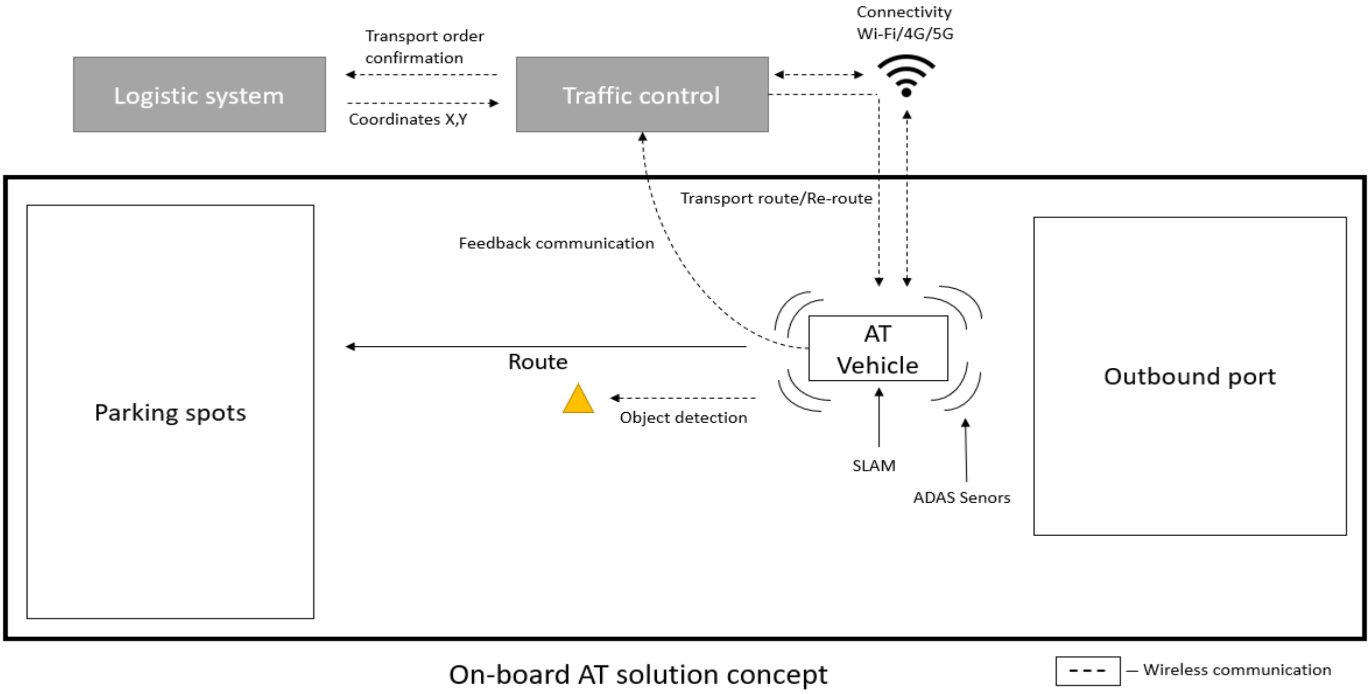


***Figure 18**: AT solution using on-board technology*

4.1.2 Off-board concept

Figure 20 illustrates the off-board concept which consist of an infrastructure system that through localization and mapping manages the vehicle. Contrary to the on-board solution, an external hardware is in control of the vehicles cognitive function and its actuators. The concept is based on controls towers being placed in the yard, where the placement and amount of the towers depends on the yard operation in question. Moreover, the control towers, suggested by the researchers, would use UWB technology in combination with Wi-Fi for accurate localization, mapping and robust connectivity. The UWB based control towers scans the yard to create a 3D map which is shared with the traffic control system. The 3D map is dynamic and thus constantly updated in accordance with the yard operation. This allows the traffic control to adapt to changes in the yard to provide the vehicle with accurate routing orders. The information process flow works similar to the on-board concept where the logistic system provides the traffic control with coordinates. However, the vehicle does not receive the coordinates in this case, instead the control tower will work in synergy with the traffic control and have access to the vehicles driving function. The off-board concept requires an additional hardware, alternatively software, to be installed in the vehicle for the purpose of an infrastructure controlling the vehicle. This allows IEA where the vehicle is managed remotely by the control towers. By localizing the vehicle and perception of the yard, the towers can plan and act in accordance with the current operation, thus being able to stop to avoid hazardous situation and simultaneously re-route the vehicle if required. Furthermore, all towers work in synergy with each other to provide accurate localization of the objects and vehicles in the yard operation.

Different technologies can be used depending on the off-board solution selected. For example, one of the suppliers uses lidar sensor with 5G or Wi-Fi connectivity for accurate perception and localization. It is stated that their technology is robust in both indoor and outdoor environments as well as in adverse weather conditions. However, the off-board concept is generalized and thus works with different technologies. The type of required technology depends on the standards of the operation in question.

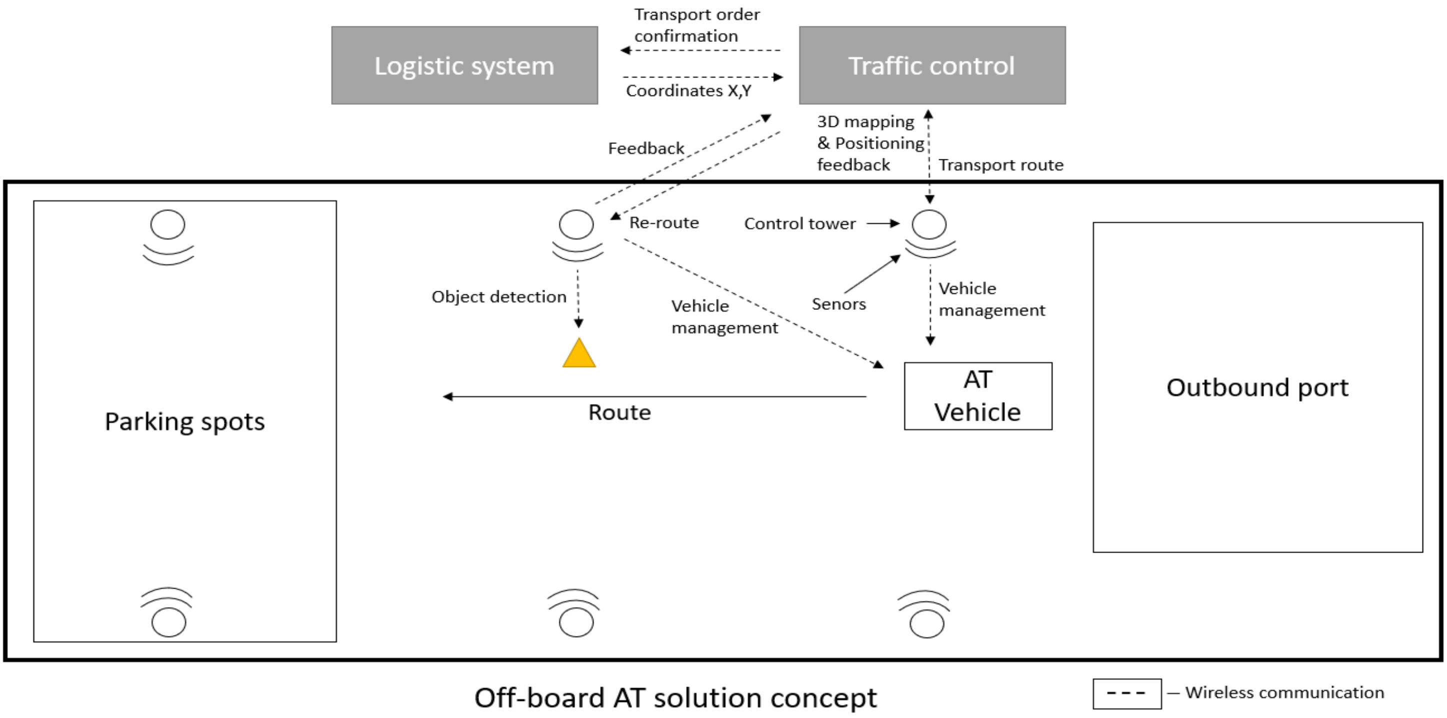
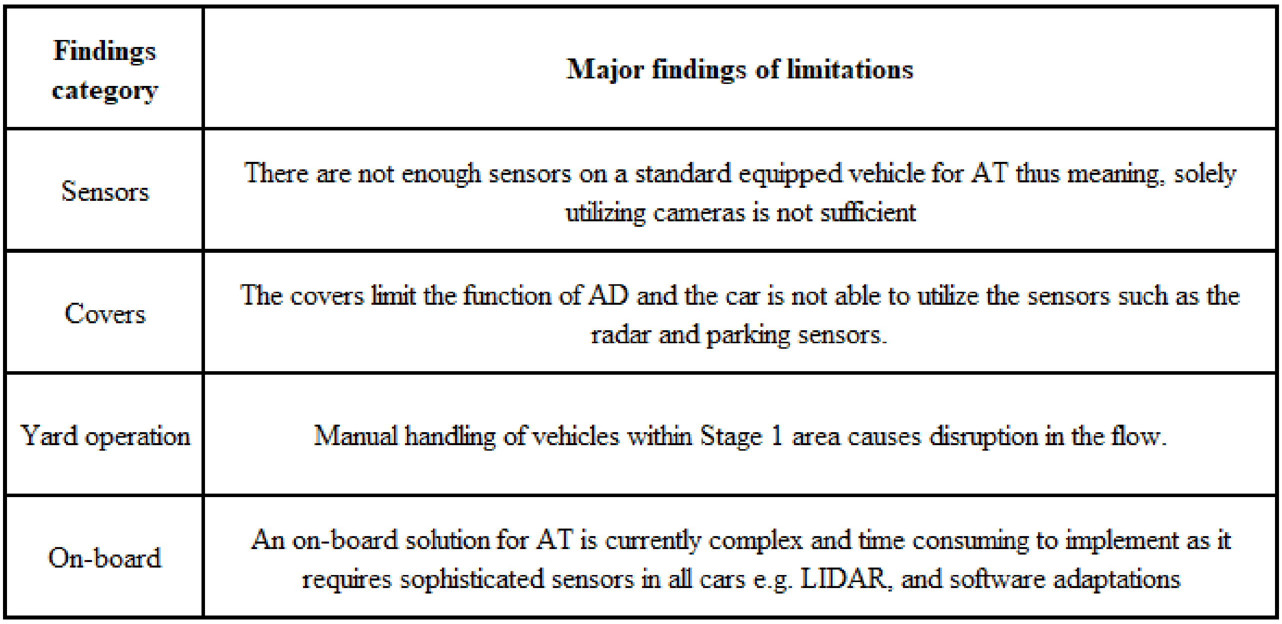


Figure 19: *AT solution using off-board technology*

4.2 AT limitations

This chapter presents the practical limitations of implementing AT in Volvo´s yard operation. According to A1 and A5 there are no theoretical limitations, in terms of the technical aspect, of implementing an AT solution. However, there are levels of feasibility of each technical utilization, such as on-board technology in contrast to off-board. Suppliers can provide off-board solution today which currently is considered as a more feasible approach compared to on-board (A1 & A5). In addition, off-board is also more robust due to it addressing the vehicles with covers on since the vehicle can be guided without the need of the sophisticated AD sensors, see Section 4.4.1. Furthermore, on-board requires additional hardware such as lidar and an internal software development which is time consuming and requires additional resources. Moreover, on-board is considered a complexity and time issue while off-board is seen as a cost issue. Thus, it is a complexity (on-board) versus cost (off-board) challenge (A2 & A4). Figure 21 summarizes the major finding of the limitations and are further justified in the sections below.



Findings category	**Major findings of limitations**
Sensors	There are not enough sensors on a standard equipped vehicle for AT thus meaning, solely utilizing cameras is not sufficient
Covers	The covers limit the function of AD and the car is not able to utilize the sensors such as the radar and parking sensors.
Yard operation	Manual handling of vehicles within Stage 1 area causes disruption in the flow.
On-board	An on-board solution for AT is currently complex and time consuming to implement as it requires sophisticated sensors in all cars e.g. LIDAR, and software adaptations

***Figure 20**: Major findings of limitations*

4.2.1 Sensors

It is not feasible to only utilize radars and/or cameras for AT, this is due to radars function not being sufficient enough solely for AD. The cameras perform worse in inclement weather including darker environments i.e. the parking yard at night with not enough lighting. Moreover, worse case scenarios are always considered and thus, for reliability purposes, a solution must address all factors and risks that entails with AT. Because of the standard equipped vehicles that are purchased comes with standard equipped sensors which are front camera and radar and rear parking sensor (ultrasound), it would be challenging to only use those as a guiding system and therefore not recommended. Furthermore, when introducing a new process in Volvos operation in general, there has to be a standard way of operating. Thus, when implementing an AT solution it has to be based on the most standard equipped vehicle, so that all vehicles are able to operate autonomously (A2 & A3).

According to A2 and A6, for an AD car to be adapted for AT is that the sensors must be fully reliable to autobrake during obstacle detection in all conditions such as weather and dark environments. Another function brought up by A2 and A6 was sensor accuracy for parking the vehicles as close as possible. Therefore, A2 and A3 are suggesting working with sensor fusion, including a lidar, and both rear and front radar and parking sensors which is not equipped on standard purchased vehicle. Sensor fusion including lidar would be able to address operating in dark environments and combined with an adjusted cognitive function of the AD software the vehicles can be adjusted for AT. This is due to that the on-board technology must work together with the traffic control, and thus needs to be integrated for communicating and exchanging data between each other.

4.2.2 FC vehicle

A significant amount of the vehicles is covered with a white cover for protection purposes, shown in Figure 22, due to long-haul truck transportation. This occurs after the cars are labeled as FC. As shown, this affects the function of the sensors because, according to A3, there are currently no studies regarding how the radars would see through the cover and if all materials affect the sensors or not. However, it is established that the cloth will affect the radars function to some degree (A3). This is concluded due to that only the front camera not being covered, and the camera cannot solely be used for autonomous drive. If the car is not able to navigate itself with the help of the AD sensors while being covered with the cloth, it is regarded as blind, and the AD function will not work. Thus, to overcome this obstacle an external guiding system such as an infrastructure system has been recommended by the interviewees (A2, A3, A4 & A5).

A6 addressed the cloths by suggesting tailoring them by making holes in the areas where the sensors and cameras are positioned. However, A5 states that this might entail other issues such as risking getting the sensors and cameras dirty during inclement weather conditions since the vehicles operate outdoors. In addition, the risk of how the cloth and the vehicle is affected when transported on long-haul trucks, due to the wind resistance in combination with dirt entering the multiple holes, are unknown. Moreover, tailoring requires the cloth supplier to make changes in their operation to provide the tailored cloths, possibly entailing increased costs which must be evaluated in the AT implementation investment.

If an on-board solution is topical, A3 suggest, for the radar, to use an angular error on objects to counteract the deviations that could occur because of the covers. This will adjust the radar to, in theory, ignore the feedback coming from the cloth. However, this requires extensive research and data collection to establish the feasibility of this approach. In addition, when the vehicle has a cover on it, the parking sensors, using ultrasound, does not work because the radio waves are traveling in between the cover and the sensor, which the interviewee also addressed with making holes in the cover (A3).

Figure 21*: Rear and front view of a vehicle equipped with all sensors with a cloth on.*

4.2.3 External factors and operators affecting the yard operation

Even though the AT solutions in Stage 1 is considered feasible due to the area being a controlled area, deviations that occur can require manual handling. This requires an operator to either walk or drive within the area of Stage 1, which entails risk that exposes both the operator and the production operation of transportation. Moreover, AT is still considered feasible with other actors operating in the area, however it requires additional risks to be addressed e.g., flow disruption which affects the alternative solutions (A4, A5 & A6). The vehicles that are covered with cloths, cannot detect an obstacle with their AD sensors. Furthermore, the vehicles with cloths can only utilize their front camera which tend to not recognize all obstacles in dark environments and inclement weather conditions and thus not recommended to solely use in AT (A2). Thus, an off-board solution is recommended as it can overview the whole Stage 1 including the different actors in the area. This allows it to manage the vehicle to break or re-route if an obstacle is in the way of the original path to designated coordinates. In addition, an off-board solution is stated to be robust to different weather conditions in theory and dark environments (A2 & A4).

4.3 Yard operation

This sub-chapter relates to the focus area in section 1.1.1 where the challenges of AT was addressed by A5 and A6.

Figure 18 illustrates the operation procedure before and after manual work is eliminated including the limitations to increase the takt time in the yard operation. Furthermore, the process steps are marked in numbers. Step 1 illustrates the vehicle existing the factory, Step 2 the parking of the vehicle and Step 3 the return of the operator. Thus, Step 3 in the process will not exist in ATs. Since an operator is no longer included in the process, the return is eliminated to the outbound port subsequently to parking the vehicle (A5 & A6).

According to A4, Stage 1 is recommended as an initial state due to it being a controlled area where only pedestrians and internal transport operates currently. However, the internal transportation which is step 3 is not related to the flow process of Stage 1 but is used as an area to pass through back to the out-bound port. The operators that work in that area is the ones returning in Step 3 by foot to continue the operation process. Thus, if AT is introduced, Step 3 is eliminated, and Stage 1 is considered as a controlled area where the risk of collision with pedestrians and other actors are excluded. In addition, the Stage 1 area will become a restricted area to pass through by other actors if AT is introduced. This allows the AT flow to operate in a constant flow without disruptions by other actors.

A5 addresses the issue of quality control when a vehicle is parked in Stage 1. Once it is parked after being transported from the outbound port, it is thereafter transported by other operators into further stages downstream i.e. next steps of the operation process. The operators downstream must perform a quality control on the Stage 1 vehicles before transporting them further, either directly to a customer or other parking spaces in the yard based on their destination e.g., long-haul rail. The issue arises when utilizing the advantages of close parking in AT, which limits the operators downstream to be able to walk around the vehicle to perform a quality control. However, since the vehicle cannot load itself on long haul freights, the operators downstream have to drive it manually after Stage 1 which becomes a discrepancy to utilize the close parking advantage. Moreover, close marking becomes more relevant as the takt time increases, due to the need of larger parking space area, which is not currently of a high importance (A5).

The interviewees from the outbound logistics stated that the different flows, actors, pedestrians, and internal transport will become the biggest challenge to overcome for implementing AT in general (A5 & A6). In addition, since one of the advantages with AT entails area utilization by cars being able to park closer to each other, performing manual task can become an issue because an operator will not be able to enter the vehicle if it is parked in between other vehicles (A5). Furthermore, A5 states that the risk of a system breakdown must be addressed before implementing AT, since the concept is substituting the operators and no manual work is available which exposes the production to the risk of disruptions. Moreover, the substitution will initially affect the three shifts of a total of 12 operators which operates in the defined Stage 1.

As of today, the vehicles are driven in speeds up to 30 km/h manually, however the speed will have to be reduced to 10-15 km/h for an AT solution as a precaution to collisions (A1, A2, A4 & A6). AT will have a positive influence on the productivity in terms of amount of produced car, however it will affect the throughput time negatively i.e., the process time of an operation, in this case from the outbound port to the parking spot. Since an AT vehicle will operate in a lower speed, it will take more time for it to arrive to designated parking space. However, due to an AT solution not requiring manual work, a vehicle can leave the outbound port before the previous vehicle have been parked. In current production state the operator that parks the vehicle must return to the outbound port to drive the next vehicle out from the port (A5 & A6). Thus, according to A2, AT allows a constant flow and there is no theoretical limit to the number of cars leaving the outbound port other than the production’s takt time, i.e., production rate in relation to the customer demand, and the parking space area. This indicates that takt time of the parking yard operation can be adapted to the factories takt time. In current production state, the factory’s takt time is matched with the number of operators in the yard operation.

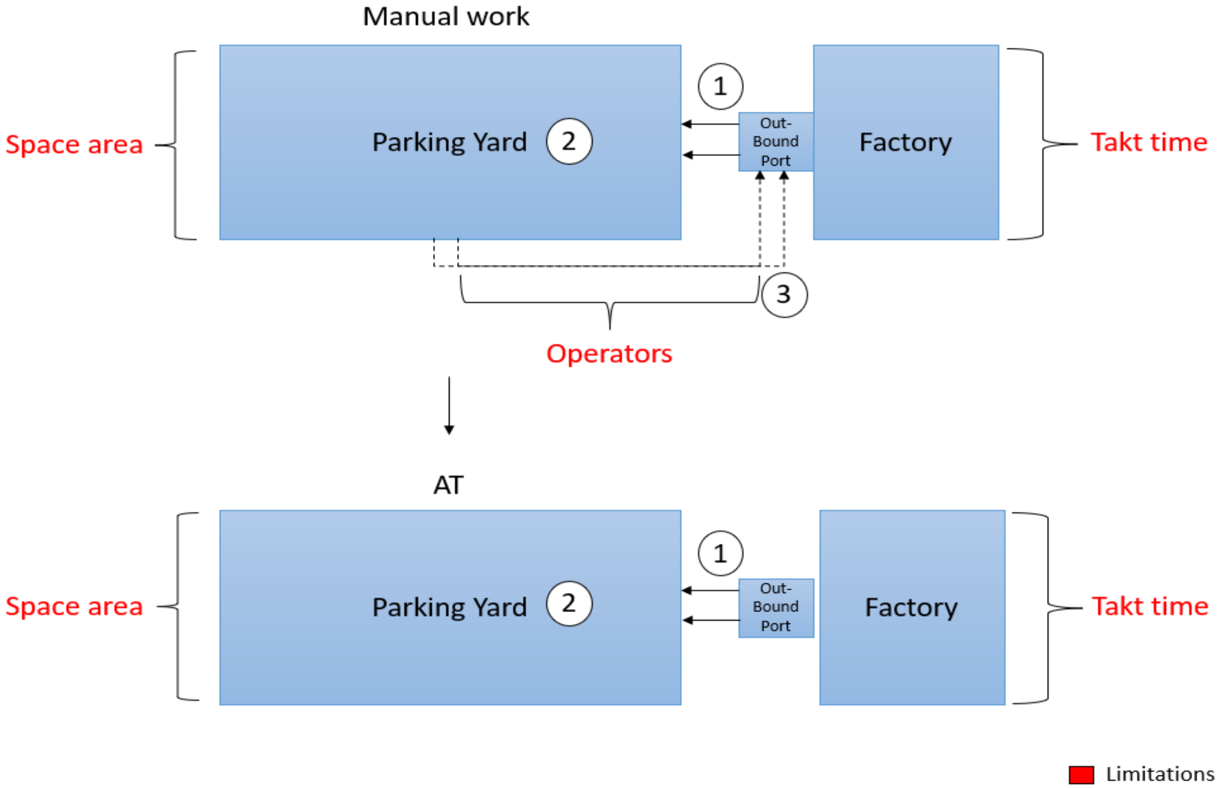


__Figure 22:__ Result of implementing the AT and the limitations of the yard operation

4.4 Regulations

The proposed solutions for AT have some challenges regarding pedestrian safety. Currently there are no regulations allowing a vehicle to operate autonomously without a driver sitting in the vehicle on Swedish roads, however this can differ between countries. Furthermore, this is not an issue since AT will operate on private property within Volvos premises, since there are already autonomous robots operating in the factory. However, the juristically issues have to be addressed to prevent collisions. Thus, an update in the work contract is required (A2, A5 & A6). However, there are regulations regarding the cyber security of vehicles operating without a driver in it. The vehicles self-operating system must meet certain requirements in order to not being able to be remotely controlled by an unauthorized party (A7).

4.5 Cyber security

According to A7, cyber security must be taken into consideration when implementing an AT solution, regarding both on-board and off-board. However, it was stated that both hardware and software of an AT solution need to adapt to the cyber security requirements. Furthermore, the interviewee states that there are same risks with both concepts, however, there are different way of approaching the risks due to the differences between the technologies.

Furthermore, A7 mentions that AT technology must be cyber certified, meaning that it meets the cyber requirements set up by the government. This favors the off-board solution since the chosen supplier of the AT solution is expected to meet these requirements. However, the cyber security department of Volvo Cars still need to assess the viability of the supplier's software and hardware against risks of an unauthorized party gaining access to the vehicles data and remote functions. The interviewee means that they still need to conduct risk assessments to ensure that the cyber security of the supplier also meets Volvos requirements. Moreover, one of the solutions to an unauthorized gaining control of the vehicles AT functions while the vehicle is still operating in the premises of Volvo Cars, is that the vehicle will be programmed to put itself in parking mode and notify the traffic control. Furthermore, UWB sensors has been evaluated as a viable technology for high accuracy for positioning in comparison to other technologies. In addition, cyber security has been investigated Wi-Fi and other hotspots. However, A7 states that handling unauthorized party that has infiltrated the system are of ease when it comes to UWB or Wi-Fi.

Although the solution is viable, the interviewee added that this would be harder to achieve outside the premises of Volvo due to the cyber security department no longer have control of the vehicle in further processes. To prevent external actors of gaining access to the AT function, A7 stated that Volvo had layers of shell protection. Meaning that the cyber security department must make additional risk assessments regarding remote access and physical access to the vehicle to evaluate the feasibility and security of the technology. These additional risk assessments that the cyber security team performs includes level of risk catalogues that has an attack tree, i.e., a graphical representation of potential attack paths used in cybersecurity to identify vulnerabilities and develop effective security measures. In addition, there are different modes that the vehicle can be perceived in which can require higher authorized individuals to work in due to safety and security reasons (A7).

A7 further states that, in comparison to off-board, the on-board technology would require longer time for research and development to develop the AT technology and adjusting it to meet the cyber security regulations to thereafter implement it. Since the vehicles at Volvo Cars are standardized and thus using the same technology, it can therefore result in one technique of cyber attacking being sufficient for the entirety of the AT vehicles. Moreover, a component integration of both internal and external hardware/software, which is required for an off-boarding solution, carries risks due to loss of cyber control, therefore a threat-risk analysis is required to protect the individuals both inside and outside the vehicle.

4.6 Finances

The implementation of autonomous transports in manufacturing settings involves investment costs (A1, A2 & A4). These costs can vary depending on the technology used and the scale of the implementation i.e., a delineated area of the yard or all of it. One of the significant costs associated with autonomous transports is the cost of software and hardware. In order for the vehicles to operate autonomously they need to be equipped with hardware such as sensors or an external navigation system (A1, A2, A4 & A6). Furthermore, the implementation of external guiding systems requires specialized infrastructure to operate efficiently. Volvo can either choose to develop the software inhouse or outsource it. This would result in significant cost differences because the outsourced software developers would require more time since they are unfamiliar with the cars' current backend system. In addition, training and education costs are also important to consider due to new roles and responsibilities that may need to be established. These roles can be data analysts or specialized technicians for maintenance. There are two types of approaches that were feasible to the researchers, off-board and on-board technologies. According to A5, Volvo currently has 12 operators over three shifts that park approximately 60 cars an hour. The operators have non-value adding time in their operation which is the return process to the outbound port from the Stage 1 area. Thus, investing into autonomous transports can improve productivity in terms of eliminating waste, reduce labor costs and improve safety in manufacturing operation due to operators not needing to cross paths with other traffic such as trucks or vehicles.

According to A2, an off-board technology has a higher investment cost compared to an on-board one. This is the case because the implementation of the off-board technology will entail costs such adaptations in the vehicle and additional hardware for the yard operations such as control towers. In addition, the higher cost is also due to the solution being outsourced which includes software development from suppliers and maintenance of the chosen technology. Furthermore, the running cost reduction by reducing the need of operators has to be balanced with costs for the off-board solution with an aim of one to two years pay-back.

The on-board technology is the cheaper alternative because it is utilizing the existing hardware in the vehicles such as radars, cameras, and other sensor systems. According to A1, an on-board solution would only require a back-end solution, i.e., software development. The expected payback for an on-board solution has not been estimated. However, it will have the potential to reduce the number of operators and running costs for transporting vehicles.

4.7 Road map

According to A4 and A6, Volvo is recommended to start with an off-bord solution using an infrastructure solution due to the fact it is an easier approach in comparison to on-board. This is due to that the standard equipped vehicles that are purchased comes with a set of sensors which currently are not sufficient for AT. The off-board technology could facilitate the understanding of what risks and costs that entails and give an idea on how profitable and safe an autonomous vehicle is. Another main challenge affecting the manufacturing plant are factory processes needing to change and adapt to the vehicle cover challenge (A2). This would entail a snowballing effect where changes continuously need to happen to the manufacturing process. An off-board solution would eliminate these challenges since it addresses the current limitations.

Furthermore, having a system being integrated that is robust, makes it a more preferable to invest in an off-board technology as a temporary solution before transitioning to an on-board solution. The off-board solution would also make it possible to discover non foreseeable/considered challenges that can be eliminated before transitioning over to an on-board solution. Thus, the off-board technology can influence other aspects such as safety, in addition to just profitability. It is expected to make a transition to the on-board technology by the year 2030, with the off-board solution in place, it would provide enough time for the R&D team to develop, test and implement on-board sensing while utilizing the advantages of AT (Volvo Source, personal communication, 2023).

***Figure 23:** Projected timeline of solution implementation*

4.8 Data triangulation

This chapter presents the findings and addresses the different approaches in order to validate the results by reviewing the observations, interviews, documents and theoretical framework.

To obtain increased trustworthiness of the results and the answers on the RQs data triangulation was conducted. The findings regard following findings categories: Sensors, Safety, Cyber security, Yard operation, Covers, On-board, and Off-board. Table 7 gives an overview of how each finding is supported by the triangulated data sources. A marked column in the table indicates that the aspect has been addressed by either complying with all data sources or not being contradicted by one or more. The supportive data sources indicate the number of sources that supports the summarization of the findings in each aspect. In addition, the data triangulation divides the aspect that address respective RQ.

Table 7: *Data triangulation of the findings in relation to the empirical and theoretical study*

		Data collection										
	Findings	Workshop	Theoretical framework	Observations	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	**Supportive data sources**
RQ1	Sensors	X	X		X	X	X	X				6
	Covers	X	X	X		X	X		X	X		7
	On-board	X	X		X	X	X	X		X	X	8
	Off-board	X	X		X	X		X			X	6
	Cyber security		X								X	2
RQ2	Safety	X	X		X	X	X	X	X	X	X	9
	Yard operation		X	X	X	X		X	X	X		7

4.8.1 RQ1 - What technological solution are most suitable for implementing AT in Stage 1 and what constraints exist?

Due to the constraints of the need to develop an AT software in-house that needs to be aligned with the cyber security regulations and requirements while also addressing the vehicle covers for an on-board solution, off-board is the most suitable for implementing in Stage 1. The technological requirements are an infrastructure system that are able to percept, plan and manage the vehicle. The suggested technology for managing the vehicles' cognitive function and the actuators are UWB control towers stationed in the yard, however other technologies can be used as long as it fulfill Volvo's requirements. The control towers need to function in accordance with a traffic control system which provides the introductions, related to the process and management of the vehicle, for the control tower to act upon. Moreover, safety is an aspect that needs to be considered, however it does not act as a constraint to an AT implementation. An AT can operate in a flow with additional actors, but it will affect the flow negatively due to disruptions since the AT vehicle need to stall, communicate with the traffic control and re-route every time it encounter an object or actor. In conclusion, off-board is recommended as an initial implementation in order to gain knowledge and experience of working with AT before transitioning to developing an on-board solution in-house. Each aspect of the findings related to RQ1 is summarized below.

Sensors: Sensor fusion including lidar, radar and camera is the recommended approach for an on-board solution. It is also recommended for off-board as a complementary feedback tool for higher accuracy in perception, localization and avoiding hazardous situations.

Covers: The covers have a negative impact on the sensors and affects AD functions sensing technology and thus not recommended for an on-board solution. The covers need to be tailored in order to make on-board feasible.

On-board: Possible to implement if vehicle covers are addressed. Lidar sensing must be included. On-board is the cheaper alternative due to in-house development, however this entails a long implementation time.

Off-board: Preferred solution due to addressing the limitations of the vehicle covers. However, an expensive option due to outsourcing but provides a short implementation time.

Cyber security: Implementation of an AT solution will need to adapt to the cyber security requirements of Volvo's while also fulfilling the governmental regulations.

4.8.2 RQ2 - What effects would an AT solution in Stage 1 have on productivity in terms of takt-time and cost savings, and safety?

Yard operation: An off-board AT solution can have both negative and positive effects on cost and safety. It was stated by the empirical study that an off-board solution would have a positive impact on cost savings due to low up-cost per vehicle, meaning the requirements of labor would be minimized. There are currently 12 operators per day that works within Stage 1, operating on the parking process. The adoption of an off-board AT solution as stated by the workshop attendees, entail significant investment costs that would be required per factory. Thus, compared to an on-board solution would be considered as expensive. In addition, it is important to note that redesigning the existing routing will not occur, thus additional costs will not be required. However, it would increase the throughput time thus affecting it negatively due to the change in vehicle speed that the cars are operating with. The qualitative study suggests that such an action would yield a positive outcome, as it would enable the acquisition of a consistent flow.

On the contrary, an on-board AT solution does not require the implementation of external hardware. However, it does require a software to support the sensors in the vehicles. Regarding the cost, due to the hardware existing in the vehicle, only a software would need to be developed or purchased to fully leverage the sensor fusion. This entails additional expenses and time for development, implementation, and maintenance of the new software. In comparison to off-board, the existing hardware could represent a cost that cannot be recovered, hence the request for further utilization of the technology. Thus, achieving two objectives simultaneously which are elimination of potential hazardous work environments and cost savings.

Safety: The use of AT would also eliminate the repetitive and hazardous tasks for the operators, thus improving the safety by reducing the risks of accidents and injuries. However, another factor to consider is the impact on the workers safety. The physical risks of accidents and injuries might be terminated, but this can pose new risks such as cyber-attacks and inadequate training of personnel. Therefore, the cost and safety depend on various factors such as the effectiveness of training and safety protocols. Lastly, an on-board solution would be cheaper and have the same constraints and challenges as an off-board solution such as pedestrian safety. However, it would require more time to implement thus short term an off-board solution is recommended by the workshop attendees to be implemented in the meantime of the on-board development. Furthermore, it was stated that a restricted area is of interest to prevent hazardous situations and disruption in the flow.

5 Discussion

This section will address the approach of the thesis by discussing the approach of execution, regarding the empirical and theory study, and the results of it. The validity and reliability of the thesis will also be discussed to ensure that the study is conducted in a logical manner and also able to be replicated with a similar or same outcome. Furthermore, the effect of an AT solution on the manufacturing of Volvo's operation will also be addressed. This includes the aspect of costs, takt-time, safety and process requirements. Lastly, future research will be discussed to provide recommendations on areas that need to be considered and further researched upon in order to implement AT.

5.1 Approach of execution

This chapter will discuss the methods used for this thesis in terms of the limitations and how they affected the findings of this thesis. This includes interviews, literature study, observations, and workshop. Furthermore, this will contribute to the generalizability of the study due to the impact of the findings through the various methods that will be discussed. The findings suggest that autonomous transportation can be applicable if the hardware/software is developed and functioning. The detailed description of the case study enhances the reliability and replicability of the study, thus increasing their applicability and relevance for different implementation areas such as multistorey parking lots or logistic companies automizing their operation.

5.1.1 Interviews

Due to AT being a relatively new research area within Volvo, none of the interviews had expertise knowledge within the area. The interviewees had an understanding of AT and what challenges needed to be addressed in order to implement AT. This led the researchers to gain knowledge of AT by interviewing multiple candidates with different expertise of both the yard operation and the vehicles' technology. Furthermore, the interview questions were used to gain a holistic view of how feasible AT is in the yard operation of Volvo in the Torslanda plant. The questions also became a guidance of what the researchers should research on in the literature study while also validating them if interviews answers align with the literature research. The interview data that was compiled provided an overview of the AT functionality and its challenges.

Without an AT expert, the researchers had to draw conclusions of the complied data. It was ensured that the conclusions drawn were not contradicted by other interviewees, however it does not mean that information is fully accurate or what solution is required. An example is the reduction in costs, the implementation- and the payback time of the investments, of which has not been calculated yet, but is agreed upon by all the interviewees. Another example is the IEA's functionality of which all the interviewees that addressed it stated that the vehicle will be able to handle hazardous situations including cyber-attacks. This can only be validated when the AT is implemented. Thus, it is important to emphasize that the results are only theoretical.

Moreover, the interviewees from the yard operation did not have any technical expertise of the vehicle which had its benefits. Since the other technical experts were niched in their area, they provided very limited answers to how AT can be implemented in the yard. Whereas the yard operation supervisor and the manager provided general ideas which were not influenced by the technological limitations. This entailed general ideas by the researchers which were thereafter adapted to the technical limitations, influenced by the technical experts and the literature.

The number of interviewees was limited to seven due to the researchers feeling satisfied with the information obtained. This was also due to towards the end of the interview phase the researchers felt that the information started to become repetitive. However, the researchers had the ability to contact the interviewees if additional information was needed after the interviews. In addition, the cyber security interview was limited to one due to the time restriction and resources of the department.

5.1.2 Literature study

Due to AT of commercial vehicles being a relatively new technology, the researchers had to take the same approach as they did with the interviews. By researching on the autonomous driving functions of a vehicle with AD technology in combination with complementary technologies, such as SLAM, UWB and Wi-Fi, they could gain an own perception of AT. During the literature study phase, interviews were conducted in parallel which as mentioned acted as a guidance for important areas to research on, which resulted in time savings for the literature study phase.

The researchers believe that the literature study provided the required prerequisites in order to generate generalized concepts of AT. However, since the thesis was limited to only present an overview of the technology, both the practicality and the functionality of the suggested systems cannot be determined until further research and at the implementation phase. Moreover, the researchers did ensure that the technology suggested was the most optimal according to the literature research. However, in addition to UWB, the researchers discovered towards the end of the thesis that there is a supplier utilizing lidar technology in their control towers in a off-board solution. When researching different infrastructure technologies regarding localization and mapping of autonomous vehicles, the papers did not address lidar in their benchmarks. Thus, the researchers chose UWB as their preferred technology as its capabilities were most suitable for managing a vehicle in terms of accuracy and safety (Opperman et al., 2004; Ullah et al., 2009). Furthermore, this implies that there can be additional alternatives technologies of which can be suitable for an off-board solution.

5.1.3 Observations

In this research, observations were used as a data collection method where the yard was studied in real time to visualize the challenges and application areas of solutions. The observations were conducted within the parking yard premise where the researchers could walk on a thin path made for returning operators. Due to the observations being limited to the Stage 1 area, only conclusions could be drawn off it thus the researchers did not have a comprehensive understanding of other locations and how pedestrians and vehicles operated there. Furthermore, meaning that this use of observations is subject to bias, as the collected data can influence the conclusion for the entirety of the yard. Due to the limitation of one location, the researchers could not mitigate the issue of bias, of generalizing AT. Considering multiple observation sites and triangulating the findings is recommended to ensure accuracy and reliability of the data collected.

5.1.4 Workshop

The workshop lasted for one hour were the researchers questioned and generated ideas from the participants. The meeting was sufficient to influence the AT concepts provided, however other aspects could have been discussed in order to address the challenges of e.g., the vehicle covers and the transitioning from off-board to on-board in the future etc. These aspects were briefly brought up in discussions, but just enough to validate the previous information obtained from the interviews. In addition, some of the interviewees were present in the workshop, however, representatives from the yard operation were not able to attend which could have affected the practical aspect which needs to be considered in the AT concept. However, the practical aspects were taken into account from the interviews with the yard personnel. Overall, the researchers were satisfied with the outcome of the workshop as it provided valuable information for answering RQ1.

5.2 On-board vs off-board

According to the theory, both on-board and off-board technologies exist and are feasible to use in practice. However, the requirements to respective approach differentiate based on the implementation. The theory recommends using sensor fusion for an on-board solution (Ziebinski et al., 2017), which should have a cognitive ability to match the standards of the operation in question. Examples to this are operating in inclement weather and dark environments, avoiding hazardous situations, V2X communication, operating in desired speed etc. In addition, the vehicle requires prerequisites which allows it to operate without limitation or influencing its cognitive ability negatively, unless it can be complemented by an alternative solution or technology.

If off-board is of relevance, the theory suggests using technologies with bandwidth that performs sufficient enough to scan the area fast enough in real-time in order to avoid hazardous situations. This means that off-board technology needs to manage the vehicle in desired speeds. For example, Wi-Fi only allows the vehicle to be managed in speeds in 3-5 km/h. Thus, higher speeds can entail collision risks due to the Wi-Fi technology not being able to process the information in order to percept the area and manage the vehicle. In addition, for the close parking function, the off-board technology requires a sufficient accuracy of the vehicles positioning. Furthermore, studies have shown that UWB technology, in comparison to other technologies with similar function, provides highly accurate data on the positioning and movement which is stated to provide reliability and safety. The speed of what the UWB technology is able to operate the vehicle is not yet determined, however, it is stated to perform better than alternative technologies.

However, the interviewees and the workshop participants did not have technical expertise of UWB or Wi-Fi due to the application of the technology for AT recently becoming topical. The interviewees and the workshop participants had expertise of the practicality and feasibility of implementing AT in their production. Thus, the researchers draw conclusions from the theory of what technology is most suitable and what is most practical from the empirical study. Moreover, due to Volvo wanting to utilize the already existing technology in the vehicle, off-board solutions is considered to entail excessive new research and costs. This is because Volvo is not familiar with the off-board technology and is not regarded as their core competence. On the contrary, on-board allows Volvo to work within their competence and develop it further, minimizing costs and the need of new competence. However, Volvo wants to stay competitive by improving margins and increasing their net income and one approach is by lowering operational costs. This brings up the implementation time requested for an AT solution. Since lowering costs is always topical, a reliable AT implementation is preferred as soon as possible. This is where an off-board solution have a leading edge, by providing a fast implementation time of approximately two years, whereas on-board is projected to around year 2030. Thus, the solutions have their advantages and drawbacks, which creates a debate of which solution is most optimal in Volvo’s time frame, costs aspects and knowledge expertise.

Furthermore, if Volvo want the preferred solution of an on-board technology, two major limitations must be addressed, sensor fusion and vehicle cover. Since the theory recommend sensor fusion, including lidar, Volvos sensing technology must mature until standard vehicles includes all sensing technologies. Thereafter, Volvo should focus on developing an on-board AT solution. thereafter, once the sensor fusion limitation is overcome, the vehicle cover must be addressed. Eliminating the vehicle covers is not an option due to the long-haul transportations, however, re-designing the cover so that it does not affect the sensors is most optional. It will either require the current supplier to make changes in their operations or sourcing of a new vehicle cover supplier. In addition, the testing of vehicles with an on-board technology with covers must be done extensively in order to assure the reliability of the AT so it functions in accordance with Volvos standards.

To emphasize the relevance of an on-board solution, it only becomes topical if Volvo includes lidar in all their vehicles. Since lidar is considered as a high-cost technology today, customers might want it excluded to reduce the cost of their purchase. Thus, creating a challenge of Volvo’s interest of re-constructing their operation by introducing AT and the customers interest of variation in their purchase. However, this can be addressed by dedicating their vehicles with lidar, including all crucial sensors for AT, in a specific factory. Whereas the vehicles without the sensor fusion technology can be produced in a separate factory using AT with an off-board technology. This allows Volvo to satisfy their interest of lowering operation costs while also providing the customer with the flexibility of tailoring their vehicle with or without lidar. However, this raises the issue of standardization where Volvo want their operations to operate the same globally. Thus, Volvo have multiple challenges to overcome for an on-board solution in contrast to off-board which is suitable for all their operations globally with a short implementation, but to a higher cost.

The off-board solution is projected to have a pay-back of one to two years. These are estimates provided by the workshop participants. There are no calculations done yet of the cost savings of eliminating the yard operators. However, the workshop participants base their projections on their experience and expertise of previous investments and therefore, they are not certain but got an idea of what the investment will result in. Moreover, the pay-back time of the off-board solution is acceptable in Volvo’s view and thus becoming a potential approach towards an AT implementation. One idea by the workshop participants is to develop the software in the vehicle that needs to communicate with the infrastructure in the off-board solution in-house, e.g. the towers that manages the vehicles. Since the off-board solution needs to be purchased from a supplier, due to lack of core competence in Volvo’s research and development department, the supplier will need to integrate a hardware device in the vehicle for it to be managed by the infrastructure system. Thus, Volvo want to both minimize cost by excluding the purchase of the hardware from the supplier and develop their own software in-house, and eliminating the potential risks of having a third-party device in their vehicle that controls the AT functions. This mitigates the dependability on the supplier if their hardware malfunctions or requires any type of maintenance while it also allows Volvo to design the software in accordance with their cyber security standards.

Furthermore, the concepts are generalized as mentioned and thus can be adjusted to fit any automotive company. However, this implicates that the automotive company in question will need the required prerequisites in terms of hardware and software technology in their vehicles for AD. In addition, the operation for AT also need to be a controlled area where possibilities of disrupting the AT flow is relatively low. Moreover, depending on the regulations and cyber security laws, implementation of AT in another country than Sweden can entail challenges that has not been discovered or addressed in this thesis.

5.3 Effects on manufacturing

The implementation of AT could affect the productivity both positively and negatively, thus the impact of the transition to autonomous technology in manufacturing was queried to most of the interviewees. The majority that was asked replied positively and it is important to note that it was also mentioned that the time for transporting the vehicle from the outbound port to the parking would be affected negatively due to the speed being decreased to a 10-15km/h from 30 km/h. However, this will not have a negative impact on the productivity since AT enables a continuous flow that is determined by the given takt-time (A1, A2, A4 & A6).

The majority believed that with a constant flow without disruptions it would be highly beneficial for the company to make the transition. Additionally, this would lead to more space availability due to no operators needing to exit the vehicle after the operation. Thus, entailing potential for an increased productivity due to the space utilization allowing more vehicles to be parked without expanding the yard space. However, it is important to note that if the system would fail and the cars would need to be driven manually which was pointed out by interviewees A5 and A6, how would the operator exit the vehicle when there is restricted spatial availability. This becomes a discrepancy in space utilization and deviation handling. Furthermore, in the event of a deviation to within the parking yard and without the availability of the previous personnel, could potentially result in a significant challenge when intervention is necessary. Thus, that has to be investigated carefully, necessary caution should be taken to ensure that attempts to enhance an existing operation should not inadvertently lead to deterioration due to discrepancies. Furthermore, regarding the vehicle cover challenge, making holes for the sensors was suggested by the interviewees A3 and A6, this solution requires an increase of accuracy for the assembly line of covers. Thus, resulting in increased throughput time of the station. Furthermore, this could also entail a higher chance of deviations due to the holes not being placed correctly or fluttering during transportation because of inclement weather.

5.4 Sustainability aspects

AT can significantly impact the sustainability aspects at Volvo by reducing waste, emissions, energy consumption and labor costs, while subsequently increasing safety and job opportunities. The well-being of people and communities are often acknowledged and regarded as the social sustainability aspect which this sub-chapter will cover.

Environmental sustainability

Volvo strives towards a zero-emission goal, an AT solution would facilitate this possibility. The vehicles transported inside the Stage 1 area will have pre-planned routes that will be taken, thus leading to the reduction of energy and fuel consumption. The vehicles will be calculated to use the most efficient speed to minimize the overall energy footprint of the manufacturing process (A1, A2, A4 & A6). Furthermore, AT can reduce emissions by the enabling of consistent driving behaviors thus resulting in less fuel consumption, and therefore affecting the greenhouse gasses emission less. Even though the effects are relatively low, this also applies for future ambitions of using AT on public roads for customer delivery which the positive effects will accumulate.

Social and economic sustainability

AT contributes to improved working conditions by reducing the need for manual labor in certain work tasks such as transportation of vehicles and returning to outbound port by foot. This leads to the operators being exposed to unnecessary risks which can be eliminated thus minimizing workplace injuries. However, as previously stated, a reduction in manual labor will occur, the displacement can further lead to social and economic insecurities for the operators. Furthermore, it is important to note that this necessarily does not bear a bad outcome since it also can generate new job opportunities in areas such as maintenance and monitoring of the AT system. Moreover, introducing AT will affect the innovation in the automotive industry by increasing the competition in both technology and lowering operation costs. This might entail the automotive industry to invest in new areas of technology which brings the possibilities of new jobs. This implies that it might have a positive impact of the economic growth of both the companies and the countries involved.

5.5 Validity and Reliability

As stated in the methodology chapter there are four types of logical tests to validate the validity and reliability of a study. First one being construct validity, this tests the accuracy of a process and the valid observations of reality (Denzin & Lincoln, 1994). This is recommended to be carried out during the data collection phase which has been done. There are three steps to carry this out for a high level of validity, multiple sources of evidence, maintaining the chain of evidence and lastly involving key informants to review the case study report. This has been executed where different data collection methods have been used such as semi-structured interviews with different departments, and internal documents have been reviewed. It is worth mentioning that the interviewees were selected to give the researchers different perspectives and angles of the research topic. However, it is important to keep in mind that the interviewees could be biased. For the researchers to maintain the chain of evidence it is vital for them to form the study so that the reader can follow the derivation of any evidence, from the research questions all the way up to the empirical study findings (Yin, 2018). The research questions have been present from the beginning and the data collected has been influenced by them. For instance, the semi-structured interview questions have been used to guide and form the questions that were going to be asked and thereafter transcribed and put into a separate document. Furthermore, the transcription of the interviews was marked with similarities between the interviewees to make it easier when presenting the results. Consequently, the empirical study findings have a clear link between the research questions thus having a clear chain of evidence. Moreover, the last step was achieved through having supervisors review the report both from the university and the company. The university supervisor reviewed the report on every other weekly basis, giving constructive feedback to the researchers. Additionally, the supervisors participated in reviewing the report continuously, thus key informants were involved.

Internal validity is used when analyzing the data and pattern matching during the thesis. Pattern matching and the comparison between the case study's empirical results with an assumption or idea regarding a solution to the presented case, this can be referred to as using the logic of pattern matching (Yin, 2018). The methodology that this thesis presents implies that the theoretical framework was refined through an iterative process that involved both pre-interview and ongoing analysis thus the thesis researchers shaped the theory chapter and grasped theoretical assumptions before the empirical findings. Anonymity was guaranteed by the researcher for the interviewees to express their real opinions regarding the subject. Thereby resulting in pattern matching being used in this thesis and it is vital for increasing the internal validity by conducting interrelated analyses of the collected data.

External validity tests to see if and how the case study's findings can be generalized. Yin (2018) states that this test has to be considered at the start of the research design, especially when designing the research questions. The author further states that the case studies must include analytic generalization. The researchers have designed the thesis to demonstrate external validity on an accurate level. This was achieved by developing a theoretical framework regarding the subject. Thereafter, the theory was triangulated with the other findings thus generalization could be achieved and stated in the discussion and conclusion of the research. However, it is important to note that generalizing could be a limitation to this case study as it was performed on a single plant of a car manufacturing company which impacts the applicability of the findings in this thesis.

Reliability, the objective with this test is to ensure that the study can be replicated and lead to the same conclusions and findings as the original study. Thus meaning, if another researcher would use the methodology presented in this thesis, they would acquire the same results (Gibbert et al., 2008). The author Yin (2018) shares the same opinion as Gibbert et al. (2008) stating that it is important to have a clear documentation for a thesis to be replicated. The researchers in this thesis developed a methodology with defined steps to ensure a high level of reliability which can be seen in figure 5. Furthermore, the interview guide was developed before the semi-structured interviews which can be seen in Appendix B, by using the same questions it is believed that other researchers can obtain the same results as this thesis. Moreover, the author states that in order to enchance the reliability of a study it is important to have a database of some sort (Gibbert et al., 2008). In this thesis all the evidence was collected and grouped in a google drive folder which contains transcriptions of the semi-structured interviews, research articles, and public and internal documentations on the case company which is vital when it comes to replication of a case study.

5.6 Future research

This thesis aimed at researching how autonomous vehicles could be utilized and implemented for the use of transportation within the automotive industry. Based on the empirical findings, it can be concluded that, AT would be of interest due to cost savings and safety, and that the implementation of an off-board solution is the more appropriate choice for this case study. Furthermore, this mainly because of the vehicle cover challenge that needs to be addressed. Regarding the cover issue which seems to be a topic of high relevance throughout the thesis, the interviewee A3 mentioned that the information and pre-study of radars was of high priority. However, a major challenge according to the interviewee was there were no current studies about radars and how they will be affected by the cover. Thus, a pre-study is recommended to be conducted so that it can be used as a preliminary stage in the process of advancement.

After the pre-study is conducted on the radars and covers, another one of future research areas would be looking into strategies to address the vehicle cover problem and an accurate cost calculation of how much it would benefit Volvo’s current state. Furthermore, after the vehicle cover issue is addressed, the implementation of AT throughout the yard can be investigated. Another challenge that Volvo currently encounters is the development of a sensor fusion software for the long-term on-board solution. The research on the back-end solution could provide the essentials for the R&D department at Volvo to further develop the software. In addition, the discrepancy of the space utilization and deviations requiring manually handling of the vehicle needs to be planned on how it should be managed.

Lastly, the interviewee A5 requested that an off topic solution that should be developed. This would enable the yard supervisors to obtain a 3D visualization of the entire parking yard with the vehicle’s statuses viewable. Meaning, the battery time that is left in the cars and which destination they are going to be transported to.

6 Conclusion

The benefit and applicability of autonomous transports has been of interest for Volvo, where the focus area was at the EOL. The main findings of the study have been crucial for selecting the most appropriate technology, which regards the following, *sensors, safety, cyber security, yard operation, covers, on-board- and off-board technology*. Through this study it is evident that a short-term off-board solution would be most optimal to Volvo since it addresses all the technological and practical challenges. However, the most preferable option in Volvo´s perspective is the on-board technology due to the ability to utilize the already existing self-driving technology of the vehicle, which implies a lower investment cost in this case. Since the vehicles offered to the customers are equipped with an AD technology, Volvo discovered the opportunity to benefit from the AD function in their outbound logistics process. However, the challenges that were identified that were identified implied currently higher risk and longer implementation time due to the vehicle covers, standardizing all required sensors for AT and the software development of the AT function. Furthermore, as for the potential of security concerns, advanced networking protocols and cybersecurity measures can be of assistance when mitigating the risks of cyber-attacks for both AT concepts. Thus, the off-board solution provides currently the alternative that best addresses the challenges stated.

It would be valuable and interesting to further explore the area of AT regarding concrete numbers due to conclusions drawn about off-board solution may be subject to bias or inaccurate projections. However, this requires implementing the preferred concepts in order to calculate actual costs and risks and gather data.

In conclusion, since Volvo want to improve cost as early as possible, it is recommended that Volvo should consider investing in an off-board strategy in order to take part of the competitive advantage of AT in terms of increasing productivity before transitioning on-board. The implementation of AT could also provide further experience for auto parking in multistorey car parks. In addition, while planning to transition to on-board, the mentioned challenges for an on-board solution must be addressed and evaluated to comply Volvo´s standards, cyber security regulations and Volvo´s requirements, and safety aspects.

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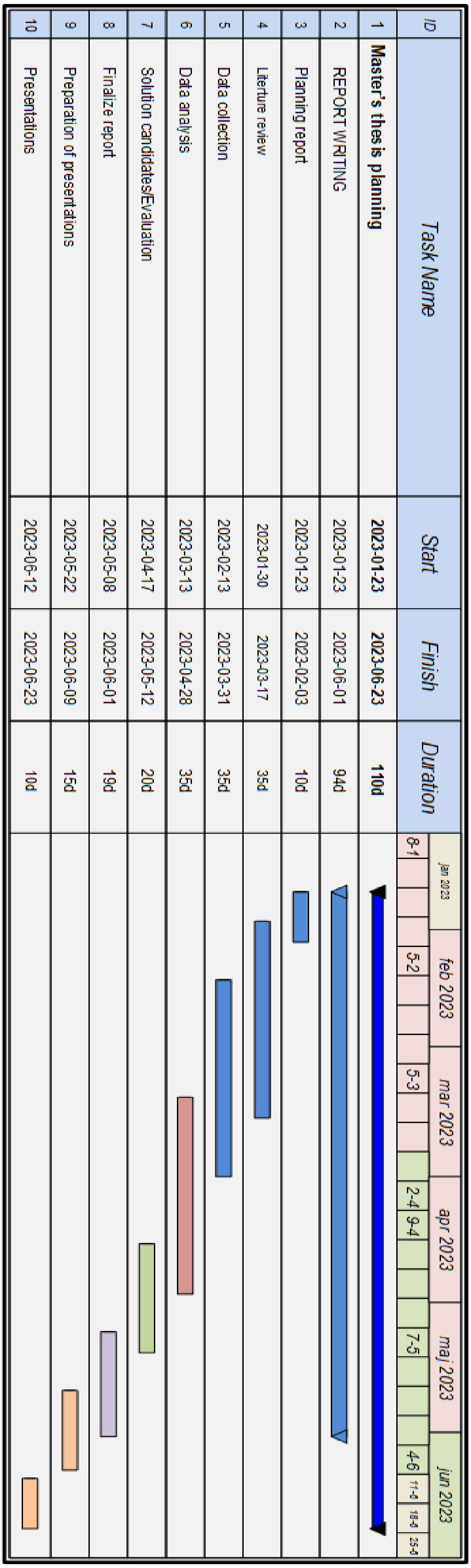
8 Appendix A – Gant chart



ID	Task Name	Start	Finish	Duration
1	**Master's thesis planning**	**2023-01-23**	**2023-06-23**	**110d**
2	REPORT WRITING	2023-01-23	2023-06-01	94d
3	Planning report	2023-01-23	2023-02-03	10d
4	Literture review	2023-01-30	2023-03-17	35d
5	Data collection	2023-02-13	2023-03-31	35d
6	Data analysis	2023-03-13	2023-04-28	35d
7	Solution candidates/Evaluation	2023-04-17	2023-05-12	20d
8	Finalize report	2023-05-08	2023-06-01	19d
9	Preparation of presentations	2023-05-22	2023-06-09	15d
10	Presentations	2023-06-12	2023-06-23	10d

9 Appendix B – Interview guide

Interviews will be held with:

1. AD experts with technical expertise
2. Production experts with knowledge of EOL processes
3. Yard logistic operation managers/supervisors
4. Cybersecurity experts

Purpose with the interviews

1. Collect the information needed for us to identify possibilities of implementing AT in stage 1.

2. Identify new challenges of implementing AT in stage 1 in addition to the previous study in 2016.

Introduction:

Purpose:

1. Explain the purpose with the interview.

2. Explain why he/she is participating as an interviewee.

Secrecy:

1. Assure the interviewee that the answers will be treated anonymously in all reports during the study.

2. That the interviewees' answers are only available to the researchers and supervisors involved in the study.

Involved parties:

1. Supervisor at Chalmers, Farook Abdullah Sultan
2. Supervisor at Volvo Cars, Joakim Pernstål (81412)
3. Master Thesis worker Ferhat Ayaz
4. Master Thesis worker Ali Fakhri

Procedure:

1. One is asking the questions and the other is taking notes/asking additional questions.

2. Inform the interviewee that some questions may be difficult to answer because they are intended for other stakeholders and are therefore nothing to worry about. It is better to answer as best you can, as there are no right or wrong answers.

3. Inform the interviewee that he/she always has the option to interrupt if he/she does not understand a question.

Presentation:

1. Present the interviewers including background, education and interest of the study.

2. If additional participants are present, then they should be presented.

3. Presentation of AT and expected results. Generate theories/hypotheses and thereafter planned actions.

Permission - recording:

1. The interviewer should always ask the interviewee if he/she allows the interview to be tape-recorded.

Introduction questions

1. Name?

2. Organizational affiliation?

3. Current position?

4. Time at my current position?

5. Experience in the current working area?

6. Time at Volvo Cars?

General Interview questions

1. How can/can't you use AT in car manufacturing?

2. For the area we are looking at (Stage 1), what potential do you see in this area in terms of using AT?

3. What characteristics does an AD car need to have to be used for AT? Can parking sensors and front camera be enough for autonomous transports?

4. What could you change in your field to make AT work?

5. How do you think AT in the Stage 1 will affect productivity?

6. What would other areas need to think about/change to make AT work?

7. What three biggest challenges do you see with running AT in production? (Constraints or conditions)

8. How do you think this should be solved?

9. Do you have anything to add?

Follow up questions for relevant candidates if needed:

1. What solution do you prefer for the parking of the vehicles in the yard and why? E.g. On-board or off-board system?

2. What type of risks do you foresee and what measures do you believe is of relevance to take to minimize them?

3. What is required for AD to be adjusted for usage of AT?

4. What type of regulations do you think will be difficult to overcome for implementing AT in the manufacturing?

Interview questions for cyber security:

1. What requirements do you have on security regarding autonomously driven cars?

2. What challenges are there with cyber security in AT?

3. How can you prevent an external actor to gain access to the AT function?

4. Does cyber security need to adapt to the function of AT, if so, how?

5. Does the requirements on cyber security regarding AT limit the implementation of on-board respective off-board and why?

6. Do you have anything to add?

Follow up questions for relevant candidates if needed:

1. Is it possible to delete the software before the car exported to the customer?

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