System Integration Testing of Advanced Driver Assistance Systems

ANDERS CIORAN
Abstract

A key factor to further improve road safety is the development and implementation of Advanced Driver Assistance Systems (ADAS) in vehicles. Common aspects of the investigated ADAS’ are their abilities of detecting and avoiding hazardous traffic situations by using sensor data and vehicle states in order to control the movement. As more complex and safety critical ADAS are developed, new test methods have to be considered. This thesis investigate how to test new ADAS from a complete vehicle level by considering aspects such as suitable test environments and traffic scenarios, and thereafter compare the results with existing testing methods. Different classifications of ADAS have been investigated and combined with own classifications considering complexity and traffic safety aspects, have made it possible to conclude and propose general test strategies for different ADAS.
Sammanfattning

En viktig faktor för att fortsätta förbättra trafiksäkerheten är genom att utveckla och implementera avancerade förarstödsfunktioner (ADAS) i fordon. Gemensamma aspekter hos de undersökta ADAS är deras förmågor att detektera och undvika farliga trafiksituations genom att nyttja sensordata och fordonstillstånd för att kontrollera fordonets förflyttning. Nya testmetoder måste övertygas eftersom nyutvecklade ADAS är mer komplexa och säkerhetskritiska. Detta arbete undersöker hur man kan testa nya ADAS från ett helfordonsperspektiv, genom att bland annat ta hänsyn till aspekter såsom lämpliga testomgivningar och trafikscenarier, och därefter jämföra resultaten med nuvarande testmetoder. Olika typer av ADAS klassifikationer har undersökt och kombinerat med egna komplexitets och trafiksäkerhets klassifikationer har gjort det möjligt att dra slutsatser och föreslå generella teststrategier för olika ADAS.
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Abbreviations

ABS  Anti-lock Braking System
ACC  Adaptive Cruise Control
ADAS Advanced Driver Assistance Systems
AEB  Autonomous Emergency Braking
BSD  Blind Spot Detection
DAS  Driver Assistance Systems
ECU  Electronic Control Unit
ESC  Electronic Stability Control
GPS  Global Positioning System
GUI  Graphical User Interface
HIL  Hardware-In-the-Loop
LCP  Lane Change Prevention
LDW  Lane Departure Warning
LKA  Lane Keep Assist
TCS  Traction Control System
TJP  Traffic Jam Pilot
TJA  Traffic Jam Assist
V2I  Vehicle-to-Infrastructure communication
V2V  Vehicle-to-Vehicle communication
V2X  Vehicle-to-vehicle and vehicle-to-infrastructure communication
VRUD Vulnerable Road User Detection
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Chapter 1

Introduction

1.1 Background

The development of safety systems used in vehicles has been progressing throughout the automotive history. In recent years, significant progress has been made, and a new era has emerged with the introduction of Advanced Driver Assistance Systems (ADAS). The introduction of ADAS has made it possible to further decrease road traffic deaths (Golias et al., 2002), as conventional safety systems have reached their full potential (Gietelink, 2007). There is no exact definition of ADAS, but a description of ADAS provided by Gietelink (2007) is given as a vehicle control system that uses environment sensors to improve driving comfort and/or traffic safety by assisting the driver in recognizing and reacting to potentially dangerous traffic situations.

The concept of systems that aid the driver by autonomous intervention is already established. These systems, known as driver assistance system (DAS), have been available since 1978 when the first electronic anti-lock braking system (ABS) was introduced. Development has since then continued, with the introduction of e.g. electronic stability control (ESC) and traction control system (TCS).

The DAS functions are characterized by the two different types of inputs; the vehicle’s states and driver input. With ADAS, the environment state is introduced as a new type of input, where environment sensors are able to detect objects located outside of the vehicle, e.g. other vehicles, pedestrians and road infrastructure. By introducing these new types of sensors, the level of complexity of the vehicle increases, which affects test and verification. The main similarities between ADAS and DAS functions with respect to test and verification can be found during final stages of the development, where both types of systems have to be implemented in real vehicles and driven on roads. Because ADAS functions use the surroundings as an input, recreating different types of traffic scenarios need to be considered. Therefore, early stages of the development of ADAS functions rely on simulations as it is not feasible to perform road tests at this stage (Abdelgawad et al., 2014). Another aspect that requires the use of simulators is the increasing safety-critical functionality of ADAS functions. E.g. autonomous emergency braking (AEB) and lane keep assist (LKA) can perform actions that endanger drivers and other road users, but can also cause significant
material damage and should not be tested on roads before extensive simulations have verified that the functions are reliable.

1.2 Problem statement

There are several aspects that need to be considered before implementing new ADAS functions. One aspect is that new ADAS functions are more complex because of more advanced algorithms and the use of new environment sensors. Furthermore, ADAS functions can control the full range of motion of the vehicle and can also perform more complex and safety critical maneuvers, e.g. hard braking and autonomous steering.

Until now, individual ADAS functions have been tested and verified separately, where the certification criterion are clear. By implementing multiple ADAS functions, interaction and communication between functions will be present as different functions can influence the same parts of the vehicle at the same time, such as vehicle movement and indicators.

Therefore, the need of test and verification from a complete vehicle perspective is increasing, and refers to test and verification of the interaction and communication between different systems and components in the vehicle. This is of vital importance, e.g. if both AEB and adaptive cruise control (ACC) are implemented, there should be no doubt that the AEB has full braking control in case of a potential collision, and should therefore override all signals provided by the ACC.

This report will address issues in system integration test of both individual and multiple interacting ADAS functions. The following will be addressed:

- How should system integration tests be designed for future ADAS functions that can influence the same components and systems at the same time.
  - Investigation of suitable test environments, where and how should the test be conducted. The location can be within an enclosed area or on public roads. The test environment can be either fully simulated or by using real vehicles. Different types of tests conducted in real vehicles can be further divided into partial simulation of sensors/environments or by not using simulations.
  - How to design different traffic scenarios with satisfying test coverage.
  - Investigation of possible conflicts that might arise during execution of multiple ADAS functions.

- How current ADAS functions are tested during different stages of development, and the impact in complete vehicle testing.
1.3 Method

Firstly, a literature study of ADAS will be conducted, with the aim of acquiring relevant material on existing ADAS functions that are currently under development. As the study progresses, parallel work and study of current ADAS test and evaluation methods will be conducted.

In parallel with the literature study, interviews of persons working with development and test of ADAS functions will be conducted in order to find differences and equalities of test and verification during different stages of the development.

The second half of this project will focus on designing different test cases for ADAS functions. One of the main purpose will be to categorize ADAS functions in order to both determine dependencies between functions and to get an overview of the resources required to test each function.

1.4 Report Outline

The following is presented by each chapter:

- **Chapter 2: Advanced Driver Assistance Systems**, introduces the reader to the concept and workings of ADAS with current and future ADAS functions.

- **Chapter 3: Testing ADAS Functions**, presents different tools and methods used for testing ADAS functions at different levels and development stages, together with different organizations that certifies ADAS functions.

- **Chapter 4: Classification of ADAS**, presents different methods used for classifying ADAS functions and conclusions that are based on a combination of the different classifications.

- **Chapter 5: Case Study 1: Autonomous Emergency Braking**, presents a case study of an already developed function that is available on the market.

- **Chapter 6: Case Study 2: Lane Change Prevention**, presents a case study of an ADAS function that is currently under development, containing test methods found in case study 1 and new proposed methods.

- **Chapter 7: Integration Testing of ADAS**, gives an overview and general test strategies for testing multiple functions that influence each other.

- **Chapter 8: Summary, Conclusion and Future Work**, summaries the report with a discussion and conclusions of how to test future ADAS functions, combined with suggestions for future work.
Chapter 2

Advanced Driver Assistance Systems

This chapter presents the concept of Advanced Driver Assistance Systems (ADAS). Descriptions and a functional decomposition of ADAS are provided, together with descriptions of both current and future ADAS functions.

2.1 Description of ADAS functions

ADAS is a term used for describing systems or functions that support the driver in their primary driving task (Knapp et al., 2009). Primary tasks are considered as input to the vehicle that can influence the vehicle’s movement, which are: acceleration, braking and steering (Geiser, 1985). The report Knapp et al. (2009) states that ADAS functions are characterized by all of the following properties:

- Detect and evaluate the vehicle environment.
- Support the driver in the primary driving task.
- Provide active support for lateral and/or longitudinal control with or without warnings.
- Direct interaction between the driver and the system.
- Use complex signal processing.

Compared to the ADAS characterization presented in the report by Knapp et al. (2009), a more general definition of ADAS will be used in this report. In this report the support to the driver can be expressed in two different forms, either by warning/indicating and/or by controlling primary tasks. Therefore, in this report an ADAS function is characterized by the both properties:

- Detect and evaluate own vehicle states, as well as other vehicles states and/or the surrounding.
- Support the driver by at least one of the following methods; warning/indicating or influencing primary tasks.
A functional decomposition of ADAS is visualized in Figure 2.1 and presents an overview of the workings of ADAS functions. By combining information about the surroundings and from driver input, an ADAS function can predict collisions and as well react to dangerous maneuvers caused by the driver. The controller seen in Figure 2.1 is the actual ADAS function which can provide information to the driver via a human-machine interface and/or influence primary tasks via actuators. The most common environment sensors providing data to ADAS functions are radars, cameras, lidar and GPS.

### 2.2 Purpose of ADAS Functions

The main purpose of ADAS functions is to aid the driver while driving, and therefore preventing accidents from occurring. This is achieved by the ADAS functions’ abilities of predicting road traffic accidents in combination with warning the driver and/or seizing control over primary driving tasks.

Road safety is a societal issue in the world, with approximate 1.2 million deaths occurring every year on the world’s roads (World Health Organization. Violence and Injury Prevention and World Health Organization, 2013). Improving road infrastructure and education are two methods used for decreasing the number of fatalities, but a report from U.S. Department of Transportation National Highway Traffic Safety Administration (2013) states that the human error is a contributing factor in 90% of all accidents.

Systems supporting the driver are therefore essential and could improve road safety by reducing the main cause of road accidents. The main type of safety systems used today are passive systems with the purpose of reducing the consequences after an accident occur, e.g. seat belt and air bag. In a report by Gietelink (2007), current passive safety systems have reached their full potential. Therefore, new safety systems have to be developed in order to further improve road safety.
2.3 Current DAS and ADAS Functions

Research and development of ADAS functions have advanced in recent years. This section presents different DAS and ADAS functions that are currently available for trucks.

2.3.1 DAS Functions

**Anti-lock braking system (ABS)**

The purpose of ABS is to prevent the wheels from locking up and avoiding loss of traction during hard braking. With ABS, when the driver applies hard braking the system uses wheel speed sensors to detect lock-ups and thereafter pulses the braking in order to avoid lock-ups. This increases the traction and the tires can maintain grip, which helps the vehicle to be able to be steered.

**Electronic stability control (ESC)**

The purpose of ESC is to improve the vehicle’s stability by reducing loss of traction. This may occur when skidding during evasive maneuvers or by losing traction on slippery roads. The ESC continuously monitors the driver’s steering input and can detect when a driver is about to lose traction by detecting if the vehicle is pointed in the intended direction. If the driver is about to lose control, the ESC automatically applies individual braking to each wheel in order to help regain control over the vehicle.

**Traction control system (TCS)**

The purpose of TCS is to limit the wheels from spinning on slippery pavement. The same wheel speed sensors used by ABS is also used by the TSC. The TSC compares all wheel speeds with the other, and if one wheel is spinning more quickly than the others, the TSC will automatically apply braking pulses to that wheel in order to reduce that wheel’s speed. However, the TSC can also reduce engine power if individual wheel braking is not enough.

2.3.2 ADAS Functions

**Adaptive cruise control (ACC)**

The purpose of ACC is to automatically adjust the vehicle’s speed in order to maintain a safe distance to another vehicle traveling ahead on the same lane. By using a combination of own vehicle states and environment sensors such as radars, the ahead vehicle’s velocity can be determined and the ACC can either increase or decrease the velocity to keep a safe distance to the ahead vehicle.

**Autonomous emergency braking (AEB)**

The purpose of AEB is to avoid collisions caused by late braking and/or braking with insufficient force. By using environment sensors, such as radars and cameras, the AEB can identify potential collisions with objects and vehicles ahead. If a critical situation is detected, the driver will be warned, and if no reaction from the driver is detected, the AEB will brake to avoid a collision (Euro NCAP, 2015a).
Lane departure warning (LDW)

The purpose of LDW is to warn the driver in the cases of inattention, which is activated if the driver unintentionally drifts toward the edge of the lane. An environment sensor such as a camera is used for providing data to the LDW, which in turn provides both audible and visual warnings to the driver (Euro NCAP, 2015c).

Platooning

Platooning is performed by driving multiple vehicles close to and behind each other, and is a way of increasing road capacity and to improve the safety, efficiency and mileage. Speed and distance control for each vehicle is done by using a longitudinal control system combined with vehicle-to-vehicle communication (V2V). By using V2V, the lateral distance between each vehicle can be decreased because the platoon can perform collective braking or accelerations because of the small communication lag.

Scania Active Prediction

The purpose of Scania Active Prediction is to decrease the fuel consumption by adjusting the vehicle’s speed depending on the topography. A combination of an advanced cruise control system, GPS and topography data enables the vehicle to adjust the cruise speed before an ascent or descent. Compared to ordinary cruise controls which tries to maintain a given speed, regardless of climbing or descending a hill, Scania Active Prediction can adjust the speed before an ascent or decent by using the momentum and therefore able to decrease the fuel consumption.

Common aspects of the described ADAS functions are in the sensor types and the type of primary driving tasks that can be controlled. The sensors are forward looking cameras and radars, while the driving tasks that can be controlled are limited to braking and accelerating. The last primary driving task, steering, cannot be controlled by current ADAS functions. However, future ADAS functions described later in this chapter have the steering capability and combined with current ADAS functions will be able to control the vehicle’s full range of motion.

2.4 Legislation

The European Commission has presented improved safety measures for vehicles. This is a part of a road safety programme with the intention of halving road deaths by 2020 (The European Commission, 2010). The following safety systems will be mandatory in most of the new trucks (The European Commission, 2009):

- Electronic Stability Control Systems (ESC) as from 1 November 2014.
- Automatic Emergency Braking Systems (AEB) as from 1 November 2015.
- Lane Departure Warning Systems (LDW) as from 1 November 2015.
2.5 Future ADAS Functions

Future ADAS functions will be more complex with increasing maneuver capabilities and the vehicles will be equipped with additional sensors providing a larger amount of sensor data. The functions will have access to the increasing amount of data about the surrounding, more efficient object recognition algorithms and the new maneuver capability autonomous steering.

With the introduction of autonomous steering, ADAS functions will be capable of controlling the full range of movement. Future functions will not necessarily be completely new and different from current functions, but most functions will be a fusion between existing functions, or a combination between existing functions with new functionality. Future functions that are not yet available to the market are described below:

Lane Change Prevention (LCP)

The purpose of LCP is to avoid dead angle accidents and accidents caused by lane changing. LCP works by two steps; firstly the driver is notified of vehicles that are located in parallel, in an adjacent lane. Secondly, if the driver tries to change lane, the LCP will intervene by applying a counteracting torque to the steering wheel in order to keep the vehicle on the current lane and therefore interrupting the lane change. LCP is a fusion between the two functions blind spot detection (BSD) and lane keep assist (LKA).

Traffic Jam Pilot (TJP)

The purpose of TJP is to aid the driver through highway traffic jams by controlling the vehicle’s motion. TJP uses radars and cameras in order to keep the vehicle in the lane and following the traffic rhythm by autonomous steering. This is a combination of the two functions adaptive cruise control (ACC) and lane keep assist (LKA), in combination with pedestrian and object detection systems.

Vehicle-to-vehicle and vehicle-to-infrastructure communication (V2X)

The purpose of V2X is to share information between vehicles and the infrastructure, e.g. information about traffic jams, dangerous traffic sections, accidents, and weather conditions. This makes it possible to calculate faster and more efficient traffic routes which avoids queues. The V2X is a communication device and cannot control the movement because it can only indicate and provide information to the driver and other ADAS functions within the vehicle.

Vulnerable road user detection (VRUD)

The purpose of VRUD is to detect and indicate the presence of nearby vulnerable road users, e.g. pedestrians and bicyclists. Furthermore, the VRUD is able to attention and warn the driver if a possible collision between a vulnerable road user and the vehicle is detected.
This is achieved by equipping the vehicle with cameras, radars and software that can detect vulnerable road users.

### 2.6 Future Outlook of the Transport Sector

By developing and implementing new ADAS functions in vehicles is by itself an advancement. However, by looking further and from a broader perspective in order to make the transport sector more efficient, the vehicles have to be connected and communicate with each other. This new technology is the cooperative Intelligent Transport Systems and Services (C-ITS), which enables communication between vehicles and the traffic infrastructure (The European Commission, 2013).

Communication devices are common and widely used within e.g. the aviation and railroad industries. With connected vehicles that are able to communicate with each other and the infrastructure, such as the traffic control, different possibilities arise. The transports can become more effective by communicating in order to make traffic smoother, avoid accidents and to choose optimal traffic routes by avoiding traffic congestions.

In order to realize connected vehicles and to make sure that communication between different vehicle manufacturers are possible, the European Commission has proposed a standardization of the Information Communications Technology by introducing a rolling plan for ICT Standardization (The European Commission, 2015).

Enabling communications between all vehicles is a significant advance because traffic congestion is a common problem in the world’s cities. Increasing the road capacity are in most cases not possible or desirable, therefore the traffic have to become more efficient by e.g. connected vehicles. This idea is not unique, but with the introduction of ADAS functions, combined with ITS makes it possible to use existing roadway capacity more efficiently.

### 2.7 Autonomous Vehicles

By combining current and future ADAS functions, autonomous vehicles can be created. However, different levels of autonomy exist as the meaning autonomous can differ. The level of autonomy is based on which and to what extent the autonomous vehicle can handle different traffic situations. Research in this area has been conducted in parallel by different vehicle companies, achieving different progresses. A few advanced autonomous vehicles driven on public roads are presented below:

**Autonomous Audi A7 Concept**

The Audi A7 concept relies on a combination of sensors to get a 360 degree view of its surrounding (Audi, 2015). Using this information, the A7 can make lane changes and passing maneuvers between speeds of 0 and 113 km/h. However, the concept vehicle has limitations and is only capable of driving autonomously in highway situations. When approaching more complex environments, such as city traffic, the driver is requested to take control of the vehicle.
Google Self-Driving Car

With over 1.8 million kilometres autonomous driving on public roads, the Google self-driving car is one of the most tested autonomous vehicle on public roads (Google, Inc, 2015). Google has created the self-driving car by retrofitting other model cars with sensors and driverless software. In comparison with the Audi A7 concept, Google’s car is able to handle some city traffic. However, the cars rely primarily on pre-programmed route data and therefore extensive road mapping has to be performed in advance.

Conclusions of current semi-autonomous vehicles can be made. Firstly, the amount of data that the vehicle’s systems need to handle is increasing because sensors e.g. cameras generate large amounts of data which has to be transmitted and processed by the on-board computer.

Furthermore, limitations in today’s autonomous vehicles exist. They are currently only able to handle certain types of traffic situations and environments, usually predetermined. As research continues, additional ADAS functions will be developed and a stepwise implementation of these functions will occur, thus making vehicles more and more autonomous.
Chapter 3

Testing ADAS Functions

3.1 Different Testing Levels

The product development process typically consists of different stages, with different aspects being considered during the development. Scania’s system testing levels are presented in Figure 3.1, which describes and visualizes different parts and levels.

Figure 3.1: The V-diagram presents different testing levels used at Scania (Adenmark, 2015). As the test level increases, the product is closer to completion.

In Figure 3.1, different testing levels used at Scania are visible. The figure visualizes different types of testing levels, depending on the stage of the development. The lowest testing level is code testing and as the development progresses, higher testing levels are
reached. This project focuses mainly on the high level complete vehicle testing, but the functional level will also be investigated.

The main differences between the complete vehicle level and the functional level are that in the functional level, only the ADAS function is tested and verified, e.g. that internal signals from sensors and commands are correct within the function. While in the complete vehicle level, the interaction between the ADAS function and the rest of the vehicle is tested and verified. This types of tests can be conducted by activating other vehicle functions, and at the same time activate the new implemented ADAS function in order to verify that the communication and interactions works as expected.

![Figure 3.2: Black box and Grey box setup](image)

The complete vehicle level testing is a form of black and/or grey box testing, depending on the conducted test and its purpose. In a report by Khan et al. (2012), three different types of box testing methods are explained: white, black and grey. In black box testing, the tester has no knowledge of the internal systems and only the fundamental aspects of the system are tested by measuring input and output. Khan et al. (2012) further describe grey box testing, in this case the tester has limited knowledge of the internal workings but can measure internal signals at different locations within the system, thus having access to more signal values.

Both black- and grey box testing are visible in Figure 3.2. As seen in the figure, in black box testing, the tester can only examine the input and output, whereas in grey box testing, the tester has access to measurement points within the box/function.

This refers back to complete vehicle testing when implementing new ADAS functions in vehicles. In this case, both black- and grey box testing can be used. For example, by verifying that the function has correct output and works as expected, then the black box testing is sufficient. However, if the signals within the ADAS function are of interest, e.g. sensor data or internal signals, grey box testing is necessary.
3.2 Tools and Methods

Different tools and methods that can be used for complete vehicle testing are presented in this section.

3.2.1 PRE-crash SCenario ANalyzer (PRESCAN)

PreScan is a simulation software tool developed by TASS International (TASS International, 2015). In PreScan, different traffic situations and scenarios can be simulated, where different surroundings, vehicle dynamics and sensors can be simulated together. This is very useful during early development stages for both ADAS and non ADAS functions, as sensor models and algorithms in functions can be tested from a complete vehicle level perspective (Gietelink et al., 2004).

How PreScan is used will be briefly explained. The user starts by designing a road map, together with the surroundings, e.g. lane markings, traffic signs and traffic lights. Thereafter vehicles can be added to the road map, together with a trajectory. Vehicle dynamics is thereafter added to each vehicle, and if needed, sensor models and ADAS algorithms. It is also possible to induce sensor disturbance to the models in order to simulate e.g. darkness, fogs, sun-blinding or snowing. When the user has set up the environment and traffic scenario, the scenario can be simulated. Thereafter the data is collected and analyzed to determine if the ADAS functions worked as supposed.

PreScan is therefore valuable during early development stages because the testing are based on models, which are not as accurate as real vehicle testing. However, this tool is powerful and makes repeatable testing of algorithms very fast on already created scenarios.

3.2.2 Laboratory Testing

Hardware-In-the-Loop (HIL) simulation is often used when testing electrical systems and is performed by connecting real hardware with each other and thereafter simulates the environment. In Scania’s HIL-lab, I-lab, actual electronic control units (ECUs) are connected to each other using the real communication network. Scania’s HIL lab is based on HIL simulators and real-time Automotive Simulation Models (ASMs) from dSPACE.

The main purpose of the HIL simulation is to test real hardware devices in a simulation environment before implementing it in real vehicles. This is a powerful tool for performing automated testing of the communication and signals between ECUs. Furthermore, the automated testing process enables a large variety of different vehicle configurations to be tested efficiently.

3.2.3 Different Vehicle Test Methods at Scania

Two types of test levels used in real vehicles have been investigated at Scania. The investigated levels are the functional level and the complete vehicle level.
**Functional Testing**

In the functional level, the main purpose is to test certain systems, e.g., an ADAS function and its internal components and signals. This is carried out by equipping a vehicle with necessary sensors and algorithms needed for the function to work. The first step is to test and verify that sensor data match the reality. It is performed by recording the road while performing tests. The driver can then compare the recordings with sensor data to verify that the sensor data correspond with the surroundings.

Furthermore, raw sensor data from certain types of sensors can be recorded and saved. This makes it possible to perform regression tests of new algorithms and software on already saved data, in order to verify that new functionality works as expected. Radar sensor data can and is often saved for the above-mentioned purpose. In the functional level, sensors are often tested separately to examine the performance, thereafter the different sensors are merged and the complete ADAS function is tested.

**Complete Vehicle Testing**

The main purpose of the complete vehicle testing is to test and verify that the interaction and communication between the vehicle and the ADAS function is working correctly. This is usually performed by equipping a vehicle with the complete ADAS function and then performing tests using two different methods. The ADAS function is either tested as is, or by simulating parts of the function while driving.

![Figure 3.3: Schematic overview of two methods used when testing ADAS functions in real vehicles. The coordinator is the vehicle’s main ECU that has access to all vehicle systems, including ADAS algorithms.](image)

A schematic overview of the two different methods is visible in Figure 3.3. The left figure, Figure 3.3a, visualizes the complete ADAS function implemented in a vehicle, thereafter tests are conducted in specific surroundings and traffic situations, depending on the purpose. In Figure 3.3b, the sensors are still on the vehicle, but not connected to the coordinator. Instead, sensor data is sent from a simulation script, and at the same time, the script receives information about the vehicle’s states. The script is also connected to a GUI (Graphical User Interface), in which different types of objects and situations can be created. Radar data is
often simulated in order to emulate other vehicles and their velocities and positions when performing tests.

This is a powerful tool as repeatable tests of different traffic scenarios can be performed without interactions between real vehicles. Therefore, one of the main advantages is that tests of dangerous situations can be simulated instead of risking injuries and vehicle damage.

### 3.2.4 AstaZero Test Site

AstaZero is an open test site and was constructed for the development, testing and certification of active safety systems. The test site is located outside of Gothenburg, Sweden, and is the first full-scale test environment for future road safety (AstaZero, 2015).

The test site consists of four different environments: rural road, city area, multi-lane road and a high-speed area. Each environment can be used for testing different scenarios in a repeatable and structured manner. AstaZero also provides communication technologies that can be used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

Other advantages of the AstaZero test site are that dynamical environments can be tested, such as traffic lights, changeable traffic signs and different types of line markings and sidewalks depending on preferences.

### 3.3 Certification Organization

Different parts of the world have different new car assessment programmes. The Global New Car Assessment Programme (Global NCAP, 2015) presents that the main purposes are to conduct independent research and testing programmes that will assess the safety and environmental characteristics of motor vehicles. Global NCAP lists different regional assessment programmes such as the European, Asian and North American. In this project, only the European new car assessment programme (Euro NCAP) has been examined.

#### 3.3.1 European New Car Assessment Programme (Euro NCAP)

The Euro NCAP is a performance assessment programme where the safety of vehicles are assessed by a five star rating system. Currently, Euro NCAP have released protocols for the following four areas: adult occupant protection, child occupant protection, pedestrian occupant protection and safety assist.

The last protocol, the safety assist (Euro NCAP, 2015b), is most relevant for this project, and will be briefly explained. In the safety assist protocol, the following types of ADAS functions are presented:

- Speed Assist Systems,
- AEB Inter-Urban Systems,
- Electronic Stability Control,
- Lane Support Systems.
Each function is presented with an introduction and description, thereafter requirements, criterion and scoring information is available. This information is detailed and comprehensive, and makes it clear how the vehicle is assessed. The different ratings are not presented in this report, but can be found in the Euro NCAP (2015b) safety assist protocol. This document is informative for vehicle manufacturers when designing different safety systems corresponding to different ratings.

### 3.3.2 RDW European Type Approvals

When a vehicle is first registered in an EU Member State, that vehicle must have a European type-approval. RDW issues these type-approvals and also issues certificates for the following ADAS functions:

- Advanced Emergency Braking system (AEB)
- Lane Departure Warning System (LDW)
- Electronic Stability Control (ESC)

The certification is based on EU-regulations, where detailed information of how the different functions are required to behave during different situations is presented. RDW’s test site is located in the Netherlands and is used by Scania for certifying ADAS functions and is the last step before market release.

### 3.4 Testing Autonomous Vehicles

By combining multiple ADAS functions, the vehicles become more autonomous. Previously in this chapter, different methods and tools used to test ADAS functions from a complete vehicle perspective was presented. During the development process, different types of tests are conducted when testing different aspects.

While developing autonomous vehicles, test sites like AstaZero will be of importance. In the test site, different traffic environments exist and make it easier and safer to test different traffic scenarios compared to setting up and performing test cases on public roads.

Safety aspects of the test driver need to be considered, e.g. should the test driver be in the vehicle and have access to a kill switch, or should the vehicle be completely remote controlled. These types of safety aspects have to be considered for different levels of autonomous vehicles.

Furthermore, real-time simulation of sensors while driving is a powerful tool as it increases the safety and make fast repeatable testing possible. The simulation combined with test sites like AstaZero gives a good platform when testing autonomous vehicles during the development. However, the need of real vehicle functional testing still exists i.e. where no simulations are used, should also be conducted in enclosed environments, such as at AstaZero. But, before conducting real tests on public roads, the above mentioned methods give a good foundation for safer and more efficient testing methods.
Chapter 4

Classification of ADAS

This chapter presents two types of classifications. Firstly, the level of driving automation describes how automated the vehicles is. Secondly, individual ADAS functions have been classified where complexity and safety aspects have been considered and thereafter combined into a combined risk estimation.

4.1 Level of Driving Automation

By implementing ADAS functions that can control primary driving tasks, an automation system is created. This leads to the issue of driving responsibilities, whether the driver or the system is responsible for the safety. The level of driving automation consists of different levels, where different driving responsibilities between the driver and the system are defined.

Three organizations have defined the level of driving automation differently, where the definition of each level differ slightly and the total number of levels are not the same. However, the same structure is used, where low levels correspond to high human responsibilities, and with increasing automation levels the safety responsibilities shifts from the driver to the system. The three presented organizations are; BASSt, NHTSA and SAE.

Bundesanstalt für Straßenwesen (BASst)

The bundesanstalt für straßenwesen (BASst) is a research institute and a part of the German government with focus in the field of road engineering. In 2012, BASst presented five different levels of automation (Tom M. Gasser et al., 2012).

National Highway Traffic Safety Administration (NHTSA)

National Highway Traffic Safety Administration (NHTSA) is a branch under the U.S. Department of Transportation, with the responsibilities of reducing deaths, injuries and economic losses resulting from motor vehicle crashes. In 2013, NHTSA defined five different levels of automation (NHTSA, 2012).

Society of Automotive Engineers (SAE)

SAE International is a global association of engineers and technical experts in various industries, with focus on the automotive industry. In 2014, SAE presented six levels of driving automation in the issued SAE Standard J3016 (2014).
### Human driver monitors the driving environment

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
</tbody>
</table>

### Automated driving system (“system”) monitors the driving environment

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>

Figure 4.1: Summary table of SAE international’s J3016 driving automation (SAE Standard J3016, 2014).

SAE international’s levels of driving automation is visible in Figure 4.1, and presents properties and aspects of the different levels, as well as an overview. The level of driving automation defined by NHTSA and BASt differs slightly, where the number of levels and level naming differs. However, the definitions are similar, and have been mapped in Figure 4.2 to correspond to the SAE levels.

<table>
<thead>
<tr>
<th>SAE</th>
<th></th>
<th></th>
<th></th>
<th>SAE</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Automation</td>
<td>Driver Assistance</td>
<td>Partial Automation</td>
<td>Conditional Automation</td>
<td>High Automation</td>
<td>Full Automation</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BASt</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver Only</td>
<td>Driver Assistance</td>
<td>Partial Autonomation</td>
<td>High automation</td>
<td>Full automation</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NHTSA</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Automation</td>
<td>Function-specific Automation</td>
<td>Combined Function Automation</td>
<td>Limited Self-Driving Automation</td>
<td>Full Self-Driving Automation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The human driver is responsible for safe operation

The “system” is responsible for safe operation

Figure 4.2: Comparison and overview of the different notations for the different levels of automation (SAE Standard J3016, 2014), (Tom M. Gasser et al., 2012), (NHTSA, 2012).
One of the key aspects of these different levels of driving automation is the transit from level 2 to 3, where the driver’s role shifts from safety control to supervisory control due to level 3’s definition where the system is responsible for monitoring the driving environment.

4.2 Functional Analyses

Functional analyses have been conducted in order to get a better overview and find dependencies between different ADAS functions. Each function has been analyzed with respect to two different aspects, safety and complexity, and are presented further in this chapter.

The materials used for the functional analyses’ are mainly based on interviews with Scania employees, where information about current and future development of ADAS functions was acquired. Current and future technology, such as different sensors that can be used by many different functions was the essential part. Two types of sensors, radars and cameras were considered of significant importance and will provide data to many functions, therefore these types of sensors will be further investigated.

4.2.1 Safety Analysis

The purpose of the safety analysis is to evaluate the traffic safety risks of maneuvers that each function can execute. Two aspects are considered in the safety analysis; either the function is activated during correct situations, or not. An example of a function that is activated during a wrong situation is if the AEB is activated by another vehicle located in the road’s shoulder and therefore not on a collision path.

The safety analysis is presented in Figure 4.3 and each function has been analyzed by considering the following aspects:

- Which types of vehicle movement can be controlled,
- Which types of damages can occur during execution,
- The danger of execution during wrong situations.
The safety analysis seen in Figure 4.3 consists of five different sections. Each section corresponds to different types of vehicle movement that can be controlled. Thereafter, ADAS functions have been placed in the corresponding section, where functions located to the left in Figure 4.3 have a lower traffic safety risk, and functions with a higher safety risk to the right. Primary driving tasks are the main aspects that were considered when making the analysis and the safety risk increases in the following order: braking, acceleration and steering. Each section in Figure 4.3 is explained below, starting with the lowest traffic safety risk:

- **Display**: The function provides audible and/or visual indications and cannot affect vehicle movement. For example warnings and signals in the dashboard.

- **Soft braking**: The function can influence the brakes by performing soft braking. E.g. by providing a small braking force when the vehicle is approaching a curve too fast.

- **Hard braking/Acceleration**: The function can control the acceleration and/or the brakes. E.g. adaptive cruise control or hard braking in order to avoid an accidents.

- **Steering**: The function can control the steering, e.g. traffic jam assist and lane change prevention.

- **Complete**: The function can control the full range of motion, i.e. autonomous vehicles.

There is a leap from hard braking/acceleration to the steering capability because by introducing functions that can control the steering, the driver’s role can change from driving to supervision. When the driver does not have an active part in the vehicle’s movement, moments of distractions might arise. Another aspect is that the driver’s reaction time increases if no active steering is needed, which also increases the possibility of an accident to occur if e.g. an ADAS system is failing.
4.2.2 Complexity Analysis

The main purpose of the complexity analysis is to get an overview of the dependencies between ADAS functions and to determine which hardware is needed when implementing new functions. Therefore, this analysis does not take the algorithm’s complexity into account, but only the hardware aspects.

The complexity analysis is presented in Figure 4.4 and each function has been analyzed by considering the following aspects:

- Which hardware is/are needed,
- Dependencies between functions.

The complexity analysis seen in Figure 4.4 consists of five different sections, each section representing different types of hardware that are needed in order to implement respective ADAS function. Furthermore, many functions in Figure 4.4 are connected by arrows, the arrows visualize that dependencies between functions exists. In most cases, more complex functions found to the right in Figure 4.4 depends on other less complex functions.

Taking lane change prevention (LCP) as an example, in order to develop and implement LCP, both lane keep assist (LKA) and blind spot detection (BSD) need to be developed. In turn, these functions rely on the implementation of new hardware such as a steering actuator and radars. The complex analysis in Figure 4.4 may also be used as a guide when choosing in which order to develop new ADAS functions.
4.2.3 Combined Risk Estimation

Both the analyses traffic safety risk and complexity have been combined into a risk estimation diagram in order to get a better overview and able to draw conclusions. The combined risk estimation diagram is visible in Figure 4.5. Each section from the two analyses has been given a number, ranging from one to five, where one represents the lowest risk/complexity. The functions have thereafter been placed in their appropriate place in the diagram, together with a number to the right. This number represents the combined risk estimation and is calculated by multiplying the function’s two numbers from each analysis.

Figure 4.5: Figure of the combined risk estimation. The number to the right of each function represents the product of the two numbers from each analyses safety safety risks and complexity.

By assigning a total risk estimation number to each function, it is possible to get an overview of how much effort that is needed when developing the functions. A higher number represents a higher traffic safety risk and complexity, therefore more resources have to be allocated when developing such functions.

By analyzing the needed resources, decisions of which functions to focus more on and whether there are enough resource capacity can be taken.
4.3 Discussion and Conclusion of Which ADAS Function to Investigate

One of the aims in this project is to investigate future ADAS functions and compare it to already implemented functions. The analyses presented in this chapter have made it possible to get a better overview and find dependencies between different functions, therefore making it possible to determine which function to investigate. The following criterion have been considered when deciding which ADAS function to investigate:

- The level of driving automation,
- Combined risk estimation analysis,
- Close in time with respect to development and implementation,
- Fusion between multiple ADAS functions.

Most ADAS functions that are currently available on the market are categorized as driving automation level 1, seen in Figure 4.1, and in the lower part of the combined risk estimation. The chosen function to investigate should therefore be more complex and have a higher combined risk estimation, compared to currently available functions. Lane change prevention (LCP) has been chosen because it is a fusion between lane keep assist (LKA) and blind spot detection (BSD), LCP is therefore more complex and has a higher combined risk estimation, and can be seen in Figure 4.4 and Figure 4.5.

Another aspect which was considered when choosing LCP is that the development of both BSD and LKA are progressing in the industry, and therefore making LCP relatively close in time with respect to development and implementation. One example is the active blind spot assist developed by Mercedes-Benz (2015).
Chapter 5

Case Study 1: Autonomous Emergency Braking

This chapter presents an existing ADAS function developed at Scania. The function autonomous emergency braking (AEB) is one of the newest function at Scania and has also been extensively tested. Detailed information about how AEB works, together with how the function has been tested at different levels are presented. Furthermore, important aspects such as advantages and disadvantages during different testing levels are mentioned.

5.1 Functional Description of AEB

Autonomous emergency braking (AEB) is an ADAS function with the purpose of avoiding accidents caused by late braking and/or braking with insufficient force, often caused by unobservant drivers or during limited road visibility.

The workings of the AEB differs slightly between different vehicle manufacturers, however a general procedure for the workings of the AEB is presented by the following four steps:

- **Step 1, Identify critical situations:** The AEB identifies critical situations by using data provided by mounted sensors, such as cameras and radars, together with information about the vehicle’s states.

- **Step 2, Warn the driver:** After a critical situation is detected, the AEB warns the driver that a collision might occur by a combination of both visual and auditory warning-signals.

- **Step 3, Soft braking:** If the driver does not acknowledge the warnings, the AEB will apply a soft braking to the vehicle, in order to further attention the driver.

- **Step 4, Hard autonomous braking:** At some point, even by applying maximum braking force, an accident cannot be avoided. Slightly before this point, the AEB will initiate hard braking in order to get the vehicle to a standstill within a certain safety distance to the object in front.
Figure 5.1: Simplified overview of the AEB’s inputs and outputs. The radar and camera provide data to the vehicle’s main computer, the coordinator. The coordinator has access to its own vehicles states and the AEB’s algorithms, and is able to send commands that influence brakes and indicators.

The AEB requires two different types of inputs to work properly. The two types are states from surrounding vehicles and the own vehicle’s states. A simplified overview of the inputs and outputs from the AEB is visible in Figure 5.1. The camera and radar provide information about surrounding vehicles. The main computer, the coordinator, provides own vehicle states such as velocity, heading, driver inputs and general information about the vehicle. The AEB’s algorithms can access this information from the coordinator and send commands for controlling brakes and indicators.

5.1.1 Aborting an AEB Intervention

The AEB intervention can be overridden and deactivated by the driver. To do this, the driver must indicate to the vehicle that he or she is aware of the situation. The driver can abort an AEB intervention by one of the following methods: brake, accelerate, activate the turn signal or by turning the steering wheel to a collision-free path.

5.1.2 Camera and Radar

The AEB uses inputs from both a camera and a radar in order to detect other vehicles and objects. The sensors are placed in the front part of the vehicle, pointing forward. By combining data from both the radar and camera, the AEB is more accurate in detecting both standstill and moving objects, compared with using only one type of sensor because each sensor has different advantages and disadvantages.

The main advantage of the radar is the ability of accurately detect moving objects, their heading and velocity, unlike the camera’s main advantage of object recognition. Therefore, it is sufficient to only use the radar for detecting moving vehicles, but for standstill vehicles, both the radar and the camera need to be used.
5.2 Testing

This section presents an investigation of how the AEB has been tested during different stages of the development at Scania. The two different testing levels functional level and complete vehicle level have been investigated. In the functional testing level, the focus is on testing the sensors, the AEB and its internal components, while in the complete vehicle testing, the interaction between the AEB and the rest of the vehicle is tested and verified.

5.2.1 Functional Testing Level

Two different types of sensors used by the AEB, camera and radar, have been investigated and is presented below, together with radar-camera fusion testing.

Radar

The radar unit and its detection algorithms are provided by a supplier. The radar detects the closest vehicles and sends the following data about them: position, heading, velocity and vehicle type. Therefore, the test at Scania verifies the radar’s capability of accurately detecting the above mentioned aspects within specified tolerances.

The test is performed by equipping a vehicle with both the radar unit and a standard camera for documentation purposes. Thereafter, the vehicle is driven in both enclosed areas and on public roads while performing tests. The tester can then verify that the radar output corresponds with the real world by comparing radar data with the recorded video.

As previously described, raw radar data can be saved and used later to regression test new algorithms and software. Therefore, raw radar data from many different types of scenarios...
and traffic situations are recorded and saved and is used in the future. The saved data can later be transferred to a computer and is used for verifying new radar algorithms. This gives the tester an efficient and powerful tool for both retesting and regression testing.

**Camera**

The camera unit does not have the same ability as the radar unit, and cannot save raw camera data. However, the schematics presented in Figure 5.2 is similar for the camera unit, excluding the raw data recording device.

The verification of the camera unit is therefore more dependent on road testing and similar to the radar testing, another camera is used to record the road for documentation purposes. The camera’s algorithms can detect the following information about nearby vehicles: position, heading, velocity and vehicle type.

Different types of situations are chosen when verifying the camera unit and its algorithms. The purpose is often to test the object recognition and road line detection algorithms; in addition the camera unit testing is often combined with radar testing. Furthermore, other types of tests are performed, such as testing what happens when the camera is obstructed or by placing the camera in front of a projector screen while projecting traffic scenarios.

**Radar-Camera Fusion**

The radar-camera fusion testing is performed by connecting both the radar and the camera to the vehicle, together with another camera which is recording the road. The ADAS algorithm is then implemented in the coordinator, which decides when to intervene by activating brakes and/or warnings signals.

The purpose of the fusion testing is to verify that both the camera and the radar detect the same vehicle states of nearby vehicles. One method that is used for testing the radar-camera fusion is by driving the equipped vehicle towards standstill or moving balloon cars. This verifies whether the AEB works correctly according to the functional description presented earlier in this chapter, in section 5.1. However, test methods from both the functional and the complete vehicle levels are overlapping in many cases, such as performing tests on public roads or by using simulation tools.

**5.2.2 Complete Vehicle Level**

In the complete vehicle test level, the interaction and communication between the AEB and the rest of the vehicle is tested and verified. The test is often performed to verify the following three aspects; the AEB executes correctly during different traffic situations, the driver can deactivate an AEB intervention and that new implemented vehicle functions and configurations does not interfere with the AEB.

Two main types of tests are conducted; firstly the tests are conducted in enclosed areas and thereafter on public roads because different surroundings are used for different purposes. In the enclosed area testing, the focus is to provoke an AEB activation, while in public road testing, the main focus is to test false positive error, i.e. if the AEB activates during wrong
situations. However, the public road testing also tests whether the AEB is activated during correct circumstances or not.

The testing can either be performed without simulating sensors, or with the sensor simulation tool described in subsection 3.2.3, which can simulate other vehicles. Simulating other vehicles is often used when testing in enclosed areas because it makes fast and repeatable testing possible. This is possible because by simulating other vehicles, many different test cases can be performed by a single driver, compared to using multiple vehicles and drivers which need to communicate and coordinate with each other while performing the tests.

When testing the AEB, a single driver can simulate vehicles in front and verify that the AEB intervenes. This is then repeated by simulating other vehicles with different velocities and positions. Another aspect that is tested is if it is possible to deactivate the AEB by the methods described in subsection 5.1.1: brake, accelerate, activate the turn signal or by changing direction.

Other aspects that can influence the sensors are considered, e.g. fuse malfunction, obstructing objects and low visibility conditions are tested to verify that the AEB deactivates due to faulty sensor inputs. Vehicle characteristics and functions should also be considered, e.g. if a trailer without ABS is connected to the tractor unit, then the AEB should remain deactivated at all times due to the possibility of jackknifing when braking hard.

When implementing new vehicle functionality that could affect the AEB, regression tests have to be performed. An example is when implementing a functionality that can influence the same parts of the vehicle as the AEB, such as braking and dashboard commands, e.g. the turn signal. Therefore, regression testing is necessary in order to verify that the AEB still works correctly after implementing new functionality that may interfere with AEB commands.

5.3 Conclusion

Several aspects of the AEB are tested in the different testing levels functional level and complete vehicle level. This is positive as errors are more likely to be found when different project groups are working independently in each of the testing levels. Other ADAS functions also use the outputs from the radar and camera sensors, and therefore the testing performed in the functional level can be adopted and used when testing other functions.

One of the main feature is the ability of simulating radar data, which makes test cases repeatable and faster to perform. The simulation tool should therefore be further developed for simulating multiple vehicles at the same time. An investigation for simulating raw camera data should be conducted in order to perform repeatable and fast testing by implementing it in the simulation tool.

The AEB is a medium safety critical function, seen in Figure 4.3, therefore false positive testing is a part of the AEB testing. Much effort has been put into eliminating false positive errors such as AEB activation during wrong situations that can cause accidents and surprise the driver. E.g. if the vehicle behind does not have enough time to stop due to the unexpected braking, or by having a driver that becomes confused and makes irrational maneuvers are aspects that need to be considered when testing ADAS functions.
Chapter 6

Case Study 2: Lane Change Prevention

The full discussion of why lane change prevention (LCP) was chosen for this case study is presented in section 4.3. Briefly, LCP was chosen because it has a higher level of automation and a higher combined risk estimation compared with already developed ADAS functions such as the AEB.

6.1 Functional Description of Lane Change Prevention

Lane change prevention (LCP) is an ADAS function with the purpose of avoiding accidents occurring when changing lanes, in many cases due to unobserved vehicles positioned in the blind spot. The LCP is a combination and fusion between the two ADAS functions blind spot detection (BSD) and lane keep assist (LKA).

The blind spot traffic scenario depicted in Figure 6.1 together with the following three steps present the workings of the LCP:

• **Step 1, Identification and indication**
  The BSD detects parallel vehicles located in the adjacent traffic lanes and indicates this to the driver.

If the BSD indicates that another vehicle is located in parallel and in an adjacent lane, and the driver tries to perform a lane change, the following will happen:

• **Step 2, Providing warnings**
  Auditory and/or visual warnings will be activated in the cabin, either in the right or left side depending on the direction of the lane change.

• **Step 3, Counteracting the driver’s steering torque**
  If the driver does not abort the lane change maneuver while the warning is active, and is still approaching the line markings, then the LCP will activate the LKA in order to counteract the driver’s steering torque to keep the vehicle within the lane.
The last step, step 3, is possible due to the use of LKA. LKA is activated by the LCP in order to abort a lane change maneuver and to remain within the initial traffic lane. A combination of both cameras and radars are needed for detecting objects and vehicles located in parallel and closely in front. Alike the AEB, front looking camera and radar can detect nearby vehicles and line markings, but the LCP requires side radars or other sensors that are able to detect vehicles positioned along the truck’s side and in parallel.

The idea is to use LCP while driving on highways or on other major roads, as smaller roads and city traffic implies complex situations that cannot yet be managed by the LCP.

6.2 Testing Lane Change Prevention

In this section, different methods that can be used for testing LCP are presented. Two different types of testing methods are presented, and the difference between them is whether simulation tools are used while performing the tests. Both methods have already been presented in the previous chapter where AEB testing was investigated. Based on the investigated methods and the literature study, suitable test methods and surroundings for testing LCP are suggested in this section.

6.2.1 Simulation Tools

Using simulation tools refers to simulating any part of, or the whole vehicle and its surroundings. Simulating tools are further categorized into complete vehicle simulation and sensor simulation.

Complete Vehicle Software Simulation

PreScan, a software simulation tool described in subsection 3.2.1 can be used for creating different virtual traffic scenarios and environments. Vehicles and their dynamics can be modeled and included in the scenario, together with attaching sensor models of cameras and radars to the vehicle. Thereafter, the LCP algorithms are included within the vehicle and the tester can start simulating a scenario.

PreScan is initially used for testing and verifying LCP algorithms because the vehicle, surroundings, sensors and scenarios are fully simulated. The scenario in Figure 6.1 can be

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Figure 6.1: Two vehicles are traveling in paralleled with the same direction, in different lanes. Vehicle 2 is positioned in the blind spot of vehicle 1.
used for initial testing by having vehicle 1 performing a lane change maneuver towards lane 2. Before and during the lane change, the tester can verify that the indications, warnings and interventions proceed according to the three steps in the functional description of lane change prevention described in section 6.1.

Sensor Simulation

The concept of simulating sensors in real vehicles is presented in the complete vehicle testing in subsection 3.2.3 and used for testing the AEB in subsection 5.2.2.

The method is to connect a computer to the vehicle’s CAN-bus and send simulated radar data directly to the coordinator, as seen in Figure 3.3b. The main purpose is to verify that the LCP behaves correctly to different radar output. By simulating the radar unit, the communication between the radar and the rest of the vehicle is verified. Two different environments have been considered and the test scenarios are the following:

- **Enclosed area, test case 1**
  - Step 1, Start and remain stationary in the middle lane of a three-lane road.
  - Step 2, Simulate another vehicle in parallel, in an adjacent lane.

The purpose of the enclosed area, test case 1 is to verify that the BSD works properly at standstill and that it indicates that a vehicle is located in parallel. The simulated vehicle should also be placed in the vehicle’s two blind spots located to the left and right while performing this test case. If the BSD works properly by giving correct indications, move on to the enclosed area, test case 2. If test case 1 is not successfully, then the BSD algorithm needs to be reconsidered.

- **Enclosed area, test case 2**
  - Step 1, Drive the vehicle in a straight line in the middle lane of a three-lane road.
  - Step 2, Simulate another vehicle in parallel, in an adjacent lane.
  - Step 3, Steer slightly towards the simulated vehicle.

The purpose of test case 2 is to verify that the whole LCP works properly. Firstly, the BSD should indicate that a vehicle is located in parallel and thereafter activate the auditory and visual warnings. Lastly, the LKA should activate and provide a counteracting steering torque to the tester.

By simulating other vehicles, many different traffic scenarios can be created because the simulated vehicle’s speed and relative distance can easily be changed to different values. Furthermore, simulating multiple vehicles on both sides at the same time should be performed in order to check that the indicators in both sides of the cabin can be active at the same time. Another aspect to consider and to test is by simulating vehicles that are approaching with substantial higher velocity in an adjacent lane. Changing lanes in such circumstances is dangerous and the LCP should intervene. All of the mentioned tests should be performed for the vehicle’s both sides.
• Public roads

In public road testing, aspects that are difficult to recreate in enclosed area testing are of interest, such as performing tests in sloped terrain, curves and during other surroundings that might interfere, e.g. overhead signs, bridges and tunnels.

Testing on public roads should be performed after enclosed area testing and one of the purpose is to further verify same aspects considered in the enclosed area testing, but in different environments. However, test cases where the LKA is activated cannot be performed when nearby public road users exist. When no other nearby road users exist and in the above mentioned surroundings, the proceedings from the enclosed area, test case 2 can be used carefully.

In both the enclosed area and public road testing, the BSD’s algorithms and the whole LKA function can be verified. The tests are not performed when having real vehicles nearby because the simulation tool is used to simulate nearby vehicles, therefore only a part of BSD is verified. In comparison, no part of LKA is simulated; therefore the whole LKA function is verified.

6.2.2 No Simulation Tools

The purpose of the road test is to test and verify that that the communication between the LCP and the rest of the vehicle is working properly. Test cases used in AEB testing can also be applied here, such as obstructing the sensors with objects and with faulty sensor outputs. The following test cases are considered in order to cover different traffic scenarios:

• Enclosed area, test case 3

  – Step 1, Start and remain stationary in the middle lane of a three-lane road.
  – Step 2, Position another stationary vehicle in parallel, in the adjacent lane.

The purpose of test case 3 is to verify the BSD’s indications for both sides of the vehicle. Additionally, two different types of tests should be performed by slightly changing this test case. In step 2, replace the stationary vehicle and perform the test for each of the following vehicle types: motorcycle, smart car, van and bus.

The second type of test is by still performing step 1, but in step 2, the parallel vehicle should be making an overtaking maneuver. Different velocities should be tested and the tests should also be performed with the different mentioned vehicle types.
• Enclosed area, test case 4

This test case is based on the traffic scenario in Figure 6.1, where two vehicles are traveling in a straight line, in parallel and in the same direction. Vehicle 1 is equipped with LCP and the procedure is the following:

– Step 1, Drive two vehicles in parallel with the same velocity, as seen in Figure 6.1.
– Step 2, Vehicle 1 makes a slow lane change maneuver toward vehicle 2 in lane 2.

This test case covers and tests all components of the LCP function. Firstly, the BDS’s indications are tested and as the lane change maneuver begins, the warnings and the LKA’s counteracting steering torque should activate.

The test case should then be slightly changed in order to perform a similar test. In step 1, instead of driving in a straight line, both vehicles should be driven on a curved road. This is necessary because curves are common in traffic roads, but also that when driving in curves, the location of the blind spot differs slightly. By driving on curved roads, the blind spot BSD’s detection algorithm is further tested because it now has to take the curvature into consideration. Another aspect to consider on curved roads is if the truck’s trailer is long, then the BSD might detect the own trailer as another vehicle.

• Public roads

The testing on public roads can either be performed when other road users are nearby or not. When no road users are nearby, test case 3 and 4 can be performed with great care.

Only the BSD’s part of the LCP can be tested when other road users are nearby, because testing the full LCP on unsuspecting road users can cause accidents. The BSD is tested by driving normal in different traffic environments such as sloped terrain, under overhead signs, on bridges and in tunnels to verify the BSD’s indications when other vehicles are in the blind spot and/or in parallel in an adjacent lane.

Another aspect to consider is infrastructure and fixed installations such as poles, traffic lights, traffic signs, guard rail, concrete blocks, buildings, traffic island etc. Testing the BSD and its outputs when it detects fixed installations has to be performed by driving nearby these installations and verify the outputs.
6.3 Aspects to Consider

The traffic surroundings are not static, therefore less common aspects and road situations have to be considered. This section presents a few less common aspects that need to be considered when testing the LCP.

- **Different types of line and lane markings**
  
  There is no standard in line and lane markings, therefore the different sizes used in different countries have to be taken into account.

- **Long and different sized vehicles**
  
  There are different sized trucks and the side radars that detect parallel vehicles need to take the own vehicle’s length into consideration. Long trailers might activate the BSD in curves because the own trailer can be perceived as another vehicle.

- **Non-highway roads**
  
  Non-highway roads such as city roads or smaller roads have tight turns. The LCP should be deactivated during these conditions because the risk of false positive errors is high.

- **Road construction**
  
  During road work, tight curves and temporary line markings are used. This can influence the radars and cameras and false positive errors can activate different ADAS functions, e.g. LCP and AEB.

- **Tunnels**
  
  In tunnels, objects such as fans, low placed signs and walls can interfere with the radar signals.

6.3.1 A Special Test Case

In the scenario presented in Figure 6.2, two vehicles are traveling in a three-lane highway when both vehicles tries to change lanes to the same lane at the same time, causing an accident.

In this case, depending on how the LCP is designed, the LCP might not get activated. Both the BSD and the LKA have to be considered. The BSD might not activate in time because the parallel distance between the vehicles is too large during the beginning of the lane change. Furthermore, the LKA might not activate the counteracting steering torque because the system might not know what to do when the vehicle is in the middle of two lanes.

This is a case when the LCP might not work as intended, depending on the tuned parameters. However all scenarios cannot be avoided and some errors will occur. E.g. if the parallel distance parameter for BSD activation is increased, then in normal lane changes, the BSD might start indicating too early due to other vehicles in the adjacent lane.
Figure 6.2: Two vehicles are traveling in the same direction when both vehicles change lanes at the same time. Vehicle 1 is equipped with LCP.

### 6.4 Conclusion

Lane change prevention (LCP) is a relatively advanced ADAS function because it has a high level of driving automation, combined with a high combined risk estimation presented in section 4.1 and subsection 4.2.3. Therefore, extensive testing in enclosed areas is required before testing on public roads.

Many ideas presented in the AEB testing can also be used when testing the LCP, such as simulating sensor data and simulating other vehicles while driving. Simulating radar sensor data is an important test method to use before using real vehicles because of the accident risk. However, by simulating sensor data, only a part of the LCP is verified and therefore a combination of both simulated and non-simulated test cases have to be performed.

A substitute to simulating vehicles is by using balloon vehicles. By using balloon vehicles, full scale tests can be performed because the risk of damages is very low. Placing a balloon vehicle in parallel and trying to perform a lane change manoeuvre verifies both the BSD and the LKA, and therefore the whole LCP is verified.

The traffic environments are also important and have different roles. By testing in enclosed areas, many different road environments cannot be tested due to limitations of the test sites. Test sites that have different traffic environments exist, e.g. AstaZero. However, public road testing also need to be performed because less common traffic environments can and should be tested, such as sloped terrain, overhead signs, bridges and tunnels.

In the enclosed area testing, the full functionality of LCP can be tested and verified compared to most public road test cases where only the BSD’s part of the LCP can be tested and verified. Therefore, public road testing should be performed for test and verification of the BSD because many different traffic situations and environments can be used, whereas in the enclosed area testing the focus should be on the LKA’s part of LCP.
Chapter 7

Integration Testing of ADAS

7.1 Combined ADAS Functional Testing

When implementing new ADAS functions, it is not sufficient to only perform individual functional testing because even if the individual function works as expected, the interaction between already implemented and new ADAS functions might behave in an unexpected manner. This section addresses this issue by providing an example of an unexpected behavior during a traffic situation when both AEB and LCP are active.

Figure 7.1: Three vehicles traveling in the same direction, vehicle 1 is equipped with both LCP and AEB. Vehicle 2 is positioned in the blind spot of vehicle 1.

The traffic scenario depicted in Figure 7.1 illustrates the need of combined ADAS functional testing. In Figure 7.1, three vehicles are traveling in the same direction with the same velocity when vehicle 3 suddenly brakes hard. The surprised driver in vehicle 1 might react in two different ways, either by changing lanes if vehicle 2 is unobserved, or by braking hard. If the driver in vehicle 1 tries to change lanes, the events in Table 7.1 might occur.

<table>
<thead>
<tr>
<th>Event</th>
<th>Action</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vehicle 3 brakes hard</td>
<td>The AEB in vehicle 1 activates</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle 1 starts the turn signal</td>
<td>The AEB in vehicle 1 deactivates</td>
</tr>
<tr>
<td>3</td>
<td>Vehicle 1 starts to change lanes</td>
<td>The LCP in vehicle 1 activates due to vehicle 2</td>
</tr>
<tr>
<td>4</td>
<td>Vehicle 1 is still in lane 1</td>
<td>Possible collision between vehicle 1 and 3</td>
</tr>
</tbody>
</table>

Table 7.1: Events and actions that might lead to an accident between vehicle 1 and 3 in Figure 7.1, when vehicle 1 tries to change lanes caused by vehicle 3’s hard braking.
The traffic scenario in Figure 7.1 together with the events in Table 7.1 illustrate that even if individual ADAS functions are working properly, the combination of functions might not work as expected. This example was chosen to illustrate an issue and is not unique for these functions. Therefore, this way of thinking has to adopted and combined ADAS functional testing have to be performed when implementing new functions.

### 7.2 General Test Strategies

Investigated test methods from the two case studies AEB and LCP led to the conclusions visible in Table 7.2. It presents the two main test methods; simulating sensor data and no use of simulations, together with both methods’ advantages, disadvantages, complexity and suitable test environments.

<table>
<thead>
<tr>
<th></th>
<th>No simulations</th>
<th>Simulating sensor data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verifies:</td>
<td>The whole function</td>
<td>Algorithms and execution</td>
</tr>
<tr>
<td>Suitable environments:</td>
<td>Enclosed areas, e.g. AstaZero</td>
<td>Flexible</td>
</tr>
<tr>
<td>Complexity:</td>
<td>Neutral</td>
<td>Increases</td>
</tr>
<tr>
<td>Advantage:</td>
<td>Verifies the whole function</td>
<td>Safer, repeatable and faster</td>
</tr>
<tr>
<td>Disadvantage:</td>
<td>Dangerous, time consuming</td>
<td>Does not test the sensors</td>
</tr>
</tbody>
</table>

Table 7.2: Comparison between two test methods; simulating sensor data and no use of simulations, used in the complete vehicle level testing.

The two test methods complement each other because simulating sensor data makes it possible to perform fast repeatable tests, which is advantageous during early stages of the development and when performing regression tests. Both the consumed time and the safety are two aspects that are benefited when simulating. However, the whole function has to be tested in a real vehicle at some point, which in turn decreases complexity and increases the need of test environments with enough versatility and is the last step before market release.

Another general test strategy has been made and is presented in Figure 7.2. This test strategy is a result of the combination of the comparison between the test methods in Table 7.2 and the combined risk estimation in Figure 4.5.
Figure 7.2: This figure is a remodelled version of Figure 4.5, which has been divided into four sections ranging from 1 to 4 and each number represents a combination of high/low traffic safety risks and complexity.

The combined risk estimation in Figure 4.5 has been divided into four sections and is visible in Figure 7.2. This has been performed in order to categorize the functions and present a general test strategy for each section. Each section is characterized by its low/high traffic safety risks and complexity values. Two type of aspects, environments and simulations have been considered for the test strategies and the conclusion is visible in Table 7.3.

<table>
<thead>
<tr>
<th>Section</th>
<th>Suitable environments</th>
<th>Simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enclosed areas</td>
<td>Minor simulations</td>
</tr>
<tr>
<td>2</td>
<td>Enclosed area, e.g. AstaZero</td>
<td>High use of simulations</td>
</tr>
<tr>
<td>3</td>
<td>Public roads</td>
<td>No simulations</td>
</tr>
<tr>
<td>4</td>
<td>All</td>
<td>Minor simulations</td>
</tr>
</tbody>
</table>

Table 7.3: Environments and simulations to be used for each section in Figure 7.2.

It is hard to propose a general test strategy for each section because it depends on the stage of the development. E.g. during early stages of the development, the simulation tool PreScan could be used to test most functions from section 1-3 that can influence the vehicle's
movement, and not for functions that only have detection/indication capabilities. Because PreScan uses software models for vehicle dynamics, sensors and thereafter simulate together with surroundings and traffic scenarios, only the ADAS algorithms are verified and not the actual sensors. Furthermore, the full extent of the communication between the sensors and the vehicle is not fully verified as it is tested in a simulating environment and not in real hardware.

The proposed test strategies in Table 7.3 are therefore intended to be used when the development has progressed and real vehicles can be equipped with the desired ADAS function. Functions in section 3 and 4 have a lower traffic safety risk and tests can be performed on public roads, compared to functions with a higher traffic safety risk from section 1 and 2 that require enclosed area testing in order to avoid accidents. However, all functions in section 4 can be performed in any environment because those functions cannot control the vehicle’s movement. However, testing blind spot detection (BSD) and VRUD have to be performed with great care and therefore enclosed area testing is recommended for initial testing. Enclosed area testing is recommended because these functions have detection and indication capabilities, therefore for the safety of surrounding vehicles and vulnerable roads users, testing these functions can not be performed on unsuspecting persons.

Functions with low complexity, section 1 and 3, depend less on simulations because only minor changes to already implemented functions are needed. But as the complexity increases, simulations are necessary in order to perform fast repeatable testing and the possibility of testing many different traffic scenarios and conditions. However, full simulations of complex functions are very complex to perform and therefore simulating a part of the function or vehicle is necessary. Complete vehicle testing by simulating sensor data should be used because of the advantages and that it is widely used, as described in previous chapters.
7.3 Proposed Testing Methodology

A testing methodology that can be used for testing new ADAS functions is proposed in this section. The methodology is based on different aspects that need to be considered when setting-up test cases.

- **Step 1, Define the purposes**
  Define which parts of the functions that need to be tested, together with defining in which conditions the function is supposed to operate.

- **Step 2, Consider affecting parameters**
  Define which parameters that can affect the testing. Aspects to consider are: influences from other functions, road types, traffic environments, weather, location, the types of sensors used and other road users.

- **Step 3, Define important traffic scenarios**
  Depending on the function’s purpose, define specific traffic scenarios and situations to consider when verifying the functionality. Both common and less common traffic scenarios should be considered. Furthermore, scenarios that might induce false positive errors should also be considered.

- **Step 4, Set-up test cases and test environments**
  Define test cases that should be considered based on the aspects in step 1-3. The test cases should be designed in such way to cover much of the function’s functionalities by using few cases that are easy, fast and repeatable in order to simplify regression testing. However, test cases containing less common traffic situations should also be designed.

  **Test environments**
  Define where and how to perform the test cases. Consider if sensor simulation tools should be used, or should no parts be simulated. Furthermore, define where to perform the test cases, such as in enclosed areas or on public roads.

- **Step 5, Evaluate the performed test cases**
  Define how to evaluate the results by comparing them with the specified requirements to evaluate whether the test cases should be redesigned or not. E.g. if the test case should be performed in enclosed areas instead of on public roads, or make the testing more effective by simulating a part of the function.
7.3.1 The Testing Methodology Applied on Platooning

An example of how to use the testing methodology is presented for the platooning function. Platooning has been chosen because it has a high combined risk estimation, 22.5 of 25, and because it uses vehicle-to-vehicle and vehicle-to-infrastructure communication (V2X). The presented test case can be both extended and limited to suit the tester’s preferences. In this test case, platooning is assumed to be almost ready for market release and the interaction between platooning and LCP is of interest. Two vehicles are traveling in a platoon in this test case, when the lead vehicle begins a lane change maneuver due to an obstacle in the current lane.

- **Step 1, Define the purposes**
  The purposes are to verify the vehicle’s object detection system, lane change capabilities and the lane change prevention (LCP) when two vehicles are traveling in a platoon and the lead vehicle begins a lane change maneuver due to an obstacle in the current lane.

- **Step 2, Consider affecting parameters**
  Parameters that affect this test case: road curvature, weather conditions, type of parallel vehicles and sensors. E.g. how far back and in parallel can the sensors detect approaching vehicles and how accurately it can compensate for the road curvature.

- **Step 3, Define important traffic scenarios**
  Two main traffic scenarios should be considered. Firstly the scenario when only the object is presence and no other road users are nearby. Secondly, the scenario when there are nearby vehicles in parallel which affects the lane change maneuver combined with an object in the road.

- **Step 4, Set-up test cases and test environments**
  This test case should be performed when no nearby road users are present.
  - Step 1, Place an object or a standstill vehicle in one lane of a two lane road.
  - Step 2, Drive a two-vehicle platoon on the same lane, towards the object.
  - Step 3, The lead vehicle makes a lane change and the last vehicle should follow.

  This test case should be performed when nearby road users are present.
  - Step 1, Place an object or a standstill vehicle in one lane of a two lane road.
  - Step 2, Drive a two-vehicle platoon on the same lane, towards the object.
  - Step 3, Drive another vehicle in parallel with the last vehicle.
  - Step 4, The lead vehicle begins a lane change.

The last test case tests what happens when one of the vehicles in the platoon cannot perform a lane change. Step 3 can be altered by changing the other vehicles position to be e.g. parallel with the lead vehicle or in parallel with both vehicles.
Test environments
These test cases should be performed in an enclosed area by using real vehicles in the platoon. However, the object and the parallel vehicle should be simulated. The parallel vehicle can either be simulated by the last and/or by the leading vehicle.

- **Step 5, Evaluate the performed test case**
  By simulating both the object and the parallel vehicle, safe, fast and repeatable tests cases can be performed. Because the only risk of collision is between the two vehicles in the platoon and in addition the test case can be set-up very fast and in different locations within the enclosed area. Furthermore, by not placing real obstacles on the test track, other test engineers can perform their own tests in parallel.

### 7.4 Future ADAS functions

The future types of ADAS functions refer to functions found in section 2.5 and are currently under development at different vehicle companies. Most future functions are level 3 driving automation functions described in section 4.1 and are therefore responsible for the safe operation. Therefore, different aspects need to be considered compared to conventional testing. Three aspects that should be further investigated are the following:

- **The safety responsibility shifts from the driver to the system**
  As the level of driving automation increases, the safety responsibility shifts to the system and other aspects have to be considered. E.g. if a sensor fault occurs, how does the system handle this without causing accidents, or if an accident occur, how to determine how and which vehicle caused the accident.

- **Stepwise implementation and testing**
  As the functions become more complex, it is hard to develop the whole function without continuous testing. Therefore, stepwise testing has to be performed, where parts of the function is tested separately and thereafter tested together. Example of such function is the LCP, where both BSD and LKA are tested separately and thereafter combined.

- **Safety aspects**
  More complex and safety critical functions will have more control of the vehicle and they will be able to control the full range of motion; therefore the tester’s safety aspects have to be prioritized. How to ensure that the tester has full control of the vehicle at all times, combined with if the tester knows which functions that are active during different testing stages and different parts of the test scenario need to be considered.
  This leads to using enclosed testing sites, such as the AstaZero, where different environments are available. Even if the test site is enclosed, the tester’s safety aspect has to be considered because the vehicle might be able to perform more safety critical maneuvers compared to conventional functions.
Chapter 8

Summary, Conclusion and Future Work

8.1 Summary

In this report, current and future ADAS functions have been investigated with respect to different types of functional classifications and test methods. Furthermore, a classification based both on complexity and safety aspects have been performed. This lead to the case study of lane change prevention (LCP), an ADAS function not yet released on the market.

The case study includes which aspects that need to be considered when testing LCP and are based on the previous case study of autonomous emergency braking (AEB), an ADAS function that has been widely tested at Scania and released to the market.

Furthermore, general test strategies for different types of ADAS functions based on the classifications have been proposed. The test strategies present ideas of how to choose the different test set-ups and which aspects to consider. Finally, a testing methodology containing five steps and aspects to consider when performing the tests have been presented, together with an example.

8.2 Conclusion

As more ADAS functions are developed, new test methods have to be considered. Firstly, future functions will be able to control the vehicle’s full range of motion, and secondly the interaction between already existing ADAS functions and future functions have to be considered. Even if individual ADAS functions work as intended, when equipping a vehicle with multiple functions, unexpected behavior might occur as seen in section 7.1.

A single test strategy cannot be applied on all ADAS functions and therefore depending on the function’s safety and complexity aspects, different test methods can be used. The common aspect when testing ADAS functions is the possibility of using simulation software, where sensor data can be simulated in real-time. This enables fast repeatable testing to be performed as a single tester can simulate other vehicles compared to the conventional way where multiple test engineers and vehicles have to be used.
Furthermore, a testing methodology has been proposed in order to perform tests in a systematic way. Other aspects to consider while performing tests is the tester’s safety because the ADAS functions can control more parts of the vehicle and its movement compared to conventional functions. Enclosed area testing, e.g. at AstaZero will have a greater role in the future as testing more complex and larger traffic scenarios have to be performed, before moving on to public road testing.

The test cases become more complex and the vehicles can control the full movement are additional aspects to consider when evaluating the tester’s safety. Therefore, additional factors will make it more complex to assess the tester’s safety in the future.

### 8.3 Future Work

A few aspects that should be considered for future work are:

- **Data collection**
  
  Investigate how to collect data from future tests, such as information about the surroundings, sensor data and the used traffic scenario. This has to be recorded in some way and thereafter synchronized with the sensor data in order to get an overview of what occurred during the test and during which circumstances the function activated.

- **Dynamical test scripts**
  
  To further improve the sensor data simulation tool, dynamical test scripts have to be developed. The purpose is to enable multiple vehicles to be simulated at the same time and also introduce the possibility of adding and removing simulated vehicles and change their properties in real-time when performing tests.

- **Synchronizing sensors while simulating**
  
  If several sensors are simulated at the same time, they have to be synchronized so that all the sensors’ data correspond with each other. E.g. if a vehicle is simulated, and the simulated sensors are not completely synchronized because of a small lag, then the simulated vehicle’s position will not be the same for all the sensors and therefore the test case will not be performed correctly.

- **Safety**
  
  If the function can control the vehicle’s full range of motion, safety aspects have to be considered to ensure the tester’s safety. Different aspects should be considered, e.g. how to conduct the test, whether the test engineer should be inside the vehicle or control it remotely. Introducing a kill switch to disable all the functions in case of emergency should also be considered.


SAE Standard J3016. Sae international taxonomy and definitions for terms related to on-road motor vehicle automated driving systems, ”levels of driving automation”, 2014.


