Development of an Integrative Graphical User Interface Concept for the Semi-Automated Lane Change Assistance System

---

Bachelor Thesis (Confidential)

Philipp Mösinger s1199579

Faculty of Engineering Technology
Industrial Design Engineering
University of Twente

Bachelor Assignment

Title: Development of an Integrative Graphical User Interface Concept for the Semi-Automated Lane Change Assistance System

Date: 01.12.2014

Organizations: University of Twente, Daimler AG

Tutor University of Twente: Assistant Professor Arie Paul van den Beukel

Tutors Daimler AG: Dr. Hans J. Küting

Peter Frank

Friedemann Kuhn

Pages: 71

Philipp Mösinger s1199579

Summary

This bachelor thesis deals with the conceptual design and visualization of an integrated graphical user interface for the semi-automated lane change assistant. The objective is to develop a concept that combines the graphical elements of an already existing concept of the semi-automated lane change assistant with the display contents of the "DISTRONIC Plus with steering assistant". According to the definition of semi-automated driver assistance systems, the driver has to permanently monitor the system as well as the vehicle environment to intervene if necessary. However, the increasing level of automation of driver assistance systems results in a change of the driver´s task from an active and regulating to a passive and monitoring task. Therefore, one objective of this thesis is to design a graphical user interface that supports the driver´s situational awareness. Due to the increasing level of automation, it is also important that the driver understands the behavior and the mode of the system in order to operate the system in the required manner. Therefore, the second main challenge is to design the graphical user interface in a way that it supports the driver's mode awareness. In order to develop an appropriate graphical user interface concept, design requirements are defined. These are based on a literature research, an analysis of the current graphical user interface concept of the semi-automated lane change assistant and different lane change scenarios. Founded on the established requirements, three integrated graphical user interface concepts are developed that differ in terms of display content, as well as in the level of detail and abstraction. For a clear visualization, the interaction sequence of each concept is illustrated by means of an animation. Based on a formative, expert-orientated evaluation, a graphical user interface concept characterized by a low level of abstraction and a reduced amount of detail showed the best result.

Samenvatting

Het onderwerp van deze bachelor opdracht is het ontwerpen en visualiseren van een geïntegreerde grafische gebruikersinterface voor de semi-automatische rijstrookwisselassistent. Het doel is een gebruiksinterface te ontwerpen dat de grafische elementen van een reeds bestaand concept voor een rijstrookwisselassistent met de elementen van de "DISTRONIC Plus" combineert. Volgens de definitie van semi-automatische rijassistentiesystemen dient de bestuurder het system en de voertuig omgeving voortdurend te monitoren en de controle over te nemen indien nodig. Het toenemende niveau van automatisering resulteert echter in een verandering van de bestuurder taak van een actieve en regulerende naar een passieve en controlerende taak. Daarom is één doel van deze opdracht de grafische gebruiksinterface zo te ontwerpen dat het situatie-bewustzijn van de bestuurder voortdurend wordt ondersteund. Vanwege de toenemende automatisering, is het bovendien belangrijk dat de bestuurder het gedrag en de modus van het geautomatiseerde system begrijpt om het voertuig op de vereiste manier te bedienen. Kortom, ook bewustzijn van systeem-modus is belangrijk om met het ontwerp te ondersteunen. Om een geschikte grafische gebruiksinterface te ontwikkelen, zijn verschillende eisen, gedefinieerd. Deze berusten op een literatuuronderzoek, een analyse van het actuele concept voor de semi-automatische rijstrookwisselassistent en verschillende rijstrookwissel scenario´s. Gebaseerd op de gestelde eisen zijn drie geïntegreerde grafische gebruikersinterfaces ontwikkelt, welke qua grafische inhoud alsmede in de mate van detail en abstractieniveau verschillen. Voor een duidelijke visualisatie, is de interactie sequentie van elk concept geïllustreerd door middel van een animatie. Uit een evaluatie met experts bleek dat een grafische gebruiksinterface, die gekenmerkt wordt door een laag niveau van abstractie en een geringe hoeveelheid aan detail, het beste resultaat opleverde.

Table of Contents

CHAPTER 1

Introduction

1.1 Organization Daimler AG

This bachelor thesis is written within the scope of the bachelor program Industrial Design Engineering at the University of Twente in cooperation with the Daimler AG. The Daimler AG is an internationally operating automotive company, headquartered in Stuttgart, Germany. [1] Daimler has production facilities on five continents and sells vehicles and services in nearly all countries of the world. It is divided into the business avenues Mercedes-Benz Cars, Daimler Trucks, Mercedes-Benz Vans, Daimler Buses and Daimler Financial Services. The Daimler AG has 275,000 employees and sold 2,3 million vehicles in the financial year 2013. This bachelor thesis is executed in the Graphical User Interaction department at the Daimler AG in Sindelfingen. The department is a part of the research and development center and is responsible for the development of innovative operating and display concepts for future cars.

1.2 Background and Objective

Mobility is a basic need of today´s life and plays an important role in our society. No other means of transport offers so much individual freedom as the automobile. This can also be seen in the growing global demand for individual mobility. Today, there are already more than 900 million vehicles on the road. [2] However, experts believe that this number will double over the next 30 years. Therefore, the demands on the transport infrastructure, as well as the individual driver will increase. Despite the rising number of vehicles, policy and automobile manufacturers are pursuing the goal to reduce the accident frequency and severity. [3] To achieve this goal, today´s vehicles are already equipped with a variety of systems that actively support the driver in the driving task. These so-called advanced driver assistance systems use various sensors to detect the environment around the vehicle. Based on the gathered information they inform, warn and even take over certain driving tasks. Vehicle manufacturers continuously research on new advanced driver assistance systems to make driving even safer and more comfortable.

An advanced driver assistance system, which is currently being developed by the Daimler AG, is a semi-automated lane change assistant. The lane change is a driving task with a high potential for error because the driver has to observe and control the front, rear and side of the vehicle. [4] In addition to that, the speed of approaching and overtaking vehicles needs to be judged correctly. It is estimated that lane change crashes account for 4 to 10 percent of all vehicle crashes. [5] Therefore, a system that supports the driver during the lane change maneuver contributes to the reduction of accidents and injuries. Current lane change assistant systems, such as the active blind spot assistant, inform the driver on the one hand by means of visual and acoustic warnings. On the other hand, they take evasive action through corrective breaking interventions in order to avoid lateral collisions. The semi-automated lane change assistant system, however, performs the lane change autonomously on the request of the driver.

The development of an advanced driver assistance system such as the semi-automated lane change assistant is a complex process that extends over several years. Next to the development of the technical function, the design of the human-machine interface plays an important role. It determines, amongst other things, how the driver operates the system, which status responses are displayed as well as where and when these are presented to the driver. All these aspects need to be well coordinated in order to support the driver´s understanding and acceptance of the system.

The demands on the driver to understand and operate these systems are rising due to an increasing number of advanced driver assistance systems. Even in today´s vehicles, the driver is exposed to a large amount of information that is generated by the different driver assistance systems. In order to keep the system´s feedback comprehensible for the driver, even with a rising number of advanced driver assistance systems, a shift from the display of individual systems towards integrated graphical user interfaces exists. Integrative graphical user interfaces combine the status feedback of different driver assistance systems in one graphical representation.

This thesis deals with the graphical visualization of the semi-automated lane change assistance system. Within the Daimler AG, different graphical user interface concepts for the semi-automated lane change assistant have already been developed and evaluated. However, these concepts consider the graphical user interface separately from other advanced driver assistance systems. The objective of this assignment is, therefore, the development of an integrated graphical user interface concept consisting of the semi-automated lane change assistant and further advanced driver assistance systems.

1.3 Structure of the Thesis

This bachelor thesis is subdivided into eight chapters. The first chapter is an introductory chapter, which outlines the background and the objective of the assignment. Within the second chapter, the subject of advanced driver assistance systems is described and analyzed. It builds the basis in order to understand what advanced driver assistance systems are, how they function and in which way they influence the task of the driver. The third chapter of this thesis outlines the methods that are chosen for the graphical user interface development. The objective is to use design methods and guidelines that help to develop a graphical user interface that makes the interaction between user and system as simple and effective as possible. The topic of the fourth chapter is the semi-automated lane change assistant. On the one hand, this chapter describes the functioning of the semi-automated lane change assistant. On the other hand, the current graphical user interface of the semi-automated lane change assistant is outlined and analyzed. Furthermore, the influence of the system on the driver is examined. Within the fifth chapter, the requirements for the design of the integrated graphical user interface are developed. The chapter considers different lane change scenarios and the intended user group in order to design a suitable interface for the semi-automated lane change assistant. Based on the established requirements, the sixth chapter outlines the concept development process from the ideation to the conceptualization of three different graphical user interfaces. The seventh chapter covers the evaluation and the improvement of the developed concepts. The last chapter reflects on the whole design process and describes recommendations for the further development of the graphical user interface concepts.

CHAPTER 2
Automotive Human-Machine Interaction

This chapter gives an introduction into the subject of advanced driver assistance systems. It covers the basic knowledge that is needed to understand what advanced driver assistance systems are and how they function. Additionally, this chapter provides an analysis of how advanced driver assistance systems influence the way driver and vehicle interact with each other.

2.1 Human-Machine System

The human-machine system is "a system in which the functions of both man and machine are interrelated and necessary for the proper system operation" [6]. Examples of human-machine systems are vehicles, aircrafts, submarines, robots, spaceships and so forth. In these systems, the human operator and the technical system form a unit to fulfill a given task. [7] In order to work efficiently together, the machine and the human operator need to interact with each other. The interaction between the human and the technical system takes place via man-machine interfaces. Man-machine interfaces are subsystems of the human-machine system and are defined as "the region or point at which a person interacts with a machine" [6]. These points allow users to operate the machine as well as observe the behavior of the machine. The transmission of information between the human and the machine takes place in two directions. [7] In the one direction, the machine communicates to the user via visual, auditory or tactile feedback. In the other direction, the transmission between the human and the machine occurs via controls. Ideally, the man-machine interface is designed in a way that it contributes to an easy, efficient, natural, and engaging interaction between the user and the machine.

2.2 Driver-Vehicle-Environment Interaction

The control of a vehicle is a human-machine interaction, which takes place in everyday life. [8] Driver, vehicle, and environment are the three parts of a system that influence each other in time and space (see Figure 1). In this system, the vehicle represents the machine, controlled by the driver through various controls. The traffic environment as the third part of the overall system includes all external factors, such as other motorists and cyclists, traffic rules, roadway arrangement, road condition, weather and traffic density.

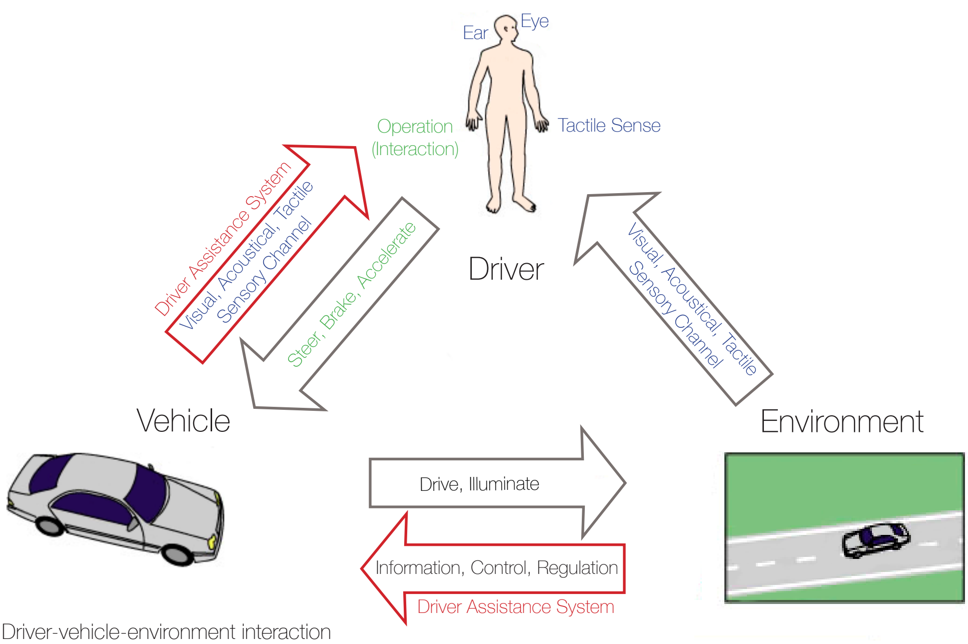


Figure 1 Driver-vehicle-environment interaction

The controls and displays of the vehicle provide information and options, which allow the driver to execute the driving task. In this human-machine system, the driver processes the system´s feedback and operates the controls of the vehicle to reach a desired destination. Thus, driver and vehicle interact via man-machine interfaces. Overall, the tasks that a driver performs while driving

can be divided into primary, secondary and tertiary tasks. [9] The primary tasks are planning, navigating, maneuvering, guiding and stabilizing the vehicle. The secondary tasks are, on the one hand, tasks that the driver performs in order to inform other road users about intended maneuvers, such as indicating a lane change. On the other hand, secondary tasks include the reaction of the driver caused by a specific situation, such as activating the windshield wiper. Tertiary tasks are executed in order to increase the driving comfort. The operation of the air conditioning is an example of a tertiary task.
The control of a vehicle is a complex task and requires diverse demands on the driver. While monitoring the traffic environment and the display elements, the driver additionally must use the various controls in short time intervals to guide the vehicle. In order to reduce these complex demands on the driver and to assist the driver during the execution of the driving task, driver assistance systems are developed.

2.3 Driver Assistance Systems

Driver assistance systems are technical systems that support the driver both actively and passively in the driving process. They offer extra help with the navigation, guidance as well as stabilization of the vehicle. [10] The goal of these systems is to assist the driver in difficult driving situations in order to reduce the number of accidents caused by human error. The term driver assistance system is a widely used term including many systems that support the driver to increase road safety. For this reason, driver assistance systems can be divided into conventional driver assistance systems and advanced driver assistance systems. Conventional driver assistance systems can only support the driver in situations that are easy to measure and evaluate. An example of a conventional driver assistance system is the anti-lock braking system, which measures the revolution of the wheels in order to detect if a wheel is locked up. Advanced driver assistance systems differ from conventional driver assistance systems by a direct connection of the vehicle with the environment. By using different kinds of sensors, advanced driver assistance systems can detect the environment around the vehicle. [11] The sensors capture information on the distance, speed, position and direction of movement of other vehicles in the environment. To capture those data, advanced driver assistance systems use different technologies, such as Radar, Lidar, Sonar, GPS, and video-based analysis. The usage and the range of the different sensor technologies can be seen in Figure 2.

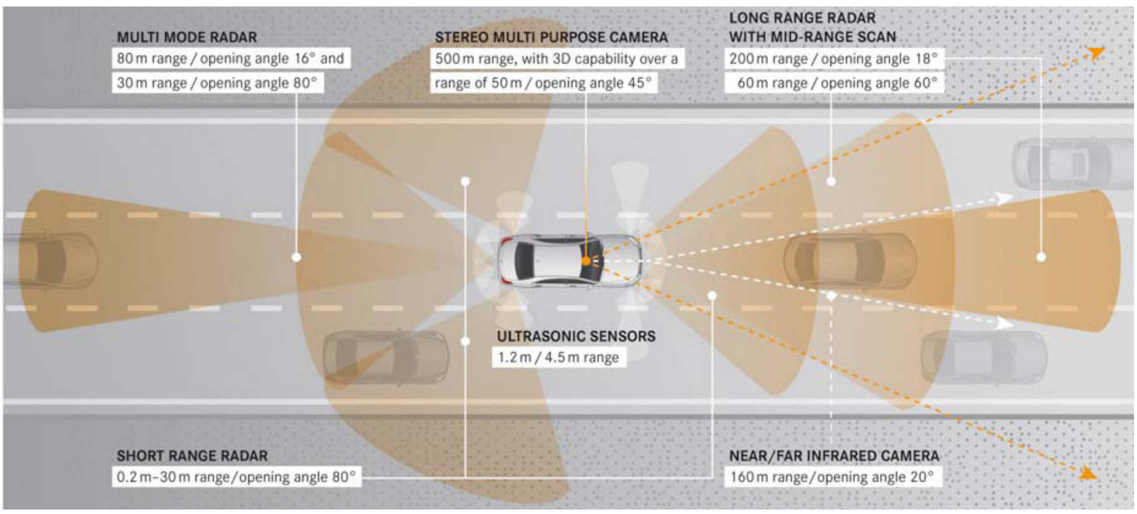


Figure 2 Usage and range of sensor technologies

Based on the subsequent interpretation of the sensor data, advanced driver assistance systems can assist the driver, or even actively intervene in the guidance of the vehicle. According to RESPONSE 3, a project of the European Union, advanced driver assistance systems must meet the following six criteria [10]:

1. *Assisting the driver in the primary driving task*
2. *Active support in the longitudinal and / or transverse control with or without warning*
3. *Environmental detection and evaluation*
4. *Use of complex signal processing*
5. *Direct interaction between driver and system*
6. *No complete takeover of the driving task*

An example of an advanced driver assistance system is the adaptive cruise control (ACC). It detects the position and velocity of a preceding vehicle by using radar sensors. Based on the detected vehicle, the adaptive cruise control adjusts the distance to the vehicle ahead automatically through engine and break interventions. Further advanced driver assistance systems are the forward collision warning, adaptive light control, lane departure warning, automatic parking, traffic sign recognition, blind spot detection, in-vehicle navigation system, driver drowsiness detection, vehicle-to-vehicle communication, on-road object recognition, collision avoidance system and night vision.

2.4 Classification of Driver Assistance Systems

2.4.1The-Three-Level-Model

Driver assistance systems can be classified according to various criteria. A commonly used categorization is based on the driving level that is supported by the assistance system. [12] According to the three-level-model of vehicle guidance, the driving task can be subdivided into three levels. [13] As shown in figure 3, the model distinguishes between the navigation, guidance, and stabilization level.

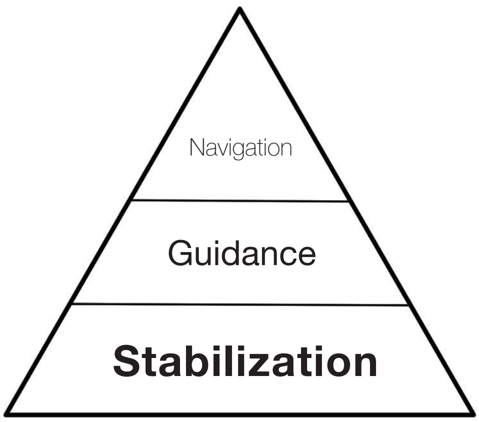


Figure 3 Levels of the driving task

On the navigation level, the driver determines the destination and the appropriate route through the transport network. On the guidance level, specific driving maneuvers are selected to reach the desired destination. Driving tasks performed on the guidance level include, amongst others, the selection of speed, the decision to overtake other road users, or the choice of the appropriate lane. The decisions taken on the guidance level are executed in the stabilization level by the proper operation of the vehicle. If the driver is overloaded with information while executing the driving task, the navigational information are neglected in order to maintain the stabilization of the vehicle. Depending on the level, a driver assistance system supports the driver, it can be classified into one of the three categories of the three-level-model: navigation level (Navigation system), guidance level (Adaptive cruise control, Lane Departure Warning, etc.) and stabilization level (Anti-lock Braking System, Electronic Stability Program, etc.).

2.4.2 Levels of Automation

A further classification of advanced driver assistance systems can be made according to the degree of automation. [14] One of the key features of automated driver assistance systems is that they take on tasks that otherwise must be performed by the driver. The Federal Highway Research Institute distinguishes in the definition of automation, referring to the driving function, between assisted, semi-automated, highly automated, and fully automated assistance (see Figure 4).

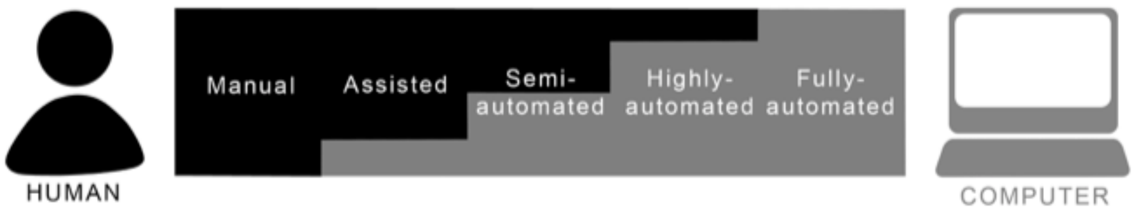


Figure 4 Levels of automation

Assistive driver assistance systems take over either the transverse or the longitudinal vehicle guidance, while the driver must perform the other driving task. Furthermore, the driver must permanently monitor the system and the traffic environment to be ready to take over the complete driving task at any time. Semi-automated driver assistance systems differ from assistive driver assistance systems by taking over the transverse and the longitudinal vehicle guidance for a specific period or in specific driving situations. Thereby, the driver still has to monitor the system and the vehicle environment to intervene if necessary. In contrast to semi-automated driver assistance systems, highly automated systems are able to recognize dangerous situations and cope with these situations independently. Therefore, the driver is not engaged to monitor the system permanently. If a driving situation exceeds the performance of a highly automated driver assistance system, it requests the driver to take over the driving task with a sufficient time reserve. Compared to highly automated driver assistance systems, fully automated driver assistance systems no longer need to be monitored by the driver. Fully automated driver assistance systems can detect all relevant hazardous situations and deal with them independently.

2.5 Channels of Interaction

The interaction between driver and advanced driver assistance system occurs via controls and displays. These provide the driver with information and help to execute the driving task safely and efficiently. Information can be transmitted from the assistance system to the driver via optical displays, audible warnings, or by haptic feedback. [15] The information provided by the driver assistance system is perceived and processed by the driver. It should be noted that not all information provided by the assistance system is also perceived and processed by the driver. [16] The perceived information subsequently leads to a driver´s action, such as the operation of the steering wheel, pedals, levers, or switches. [15] The man-machine interfaces between the driver and driver assistance system can be divided into displays and controls. In this classification, displays represent the activator of the human information processing process and the controls serve as the executing part. Since the focus of this work is on the development of a graphical user interface concept, controls are not further discussed in the following. Instead, possible display areas for advanced driver assistance systems are the focus of this study.

2.5.1 Display Elements for Advanced Driver Assistance Systems

For the display of advanced driver assistance systems there are three possible areas in a vehicle.[17] The first region is the instrument cluster, which represents the main information unit for the driver. It presents all relevant driving information to the driver at the edge of the primary field of view. While electromechanical instruments are primarily used in conjunction with small graphic displays, recent developments such as the increase in driving functions and the development of new display technologies have led to the replacement of these instruments with large graphic displays (see figure 5). The advantage of large graphic displays is that the space of the instrument cluster can be used more flexibly. Depending on the driving situation or the driver´s preference, elements within the instrument cluster can be displayed or faded out.

Figure 5 Tesla Model S digital instrument cluster

The second display area for advanced driver assistance systems is the windshield. Head-up displays make it possible to display relevant driving information directly in the driver´s primary field of view (see figure 6). The information shown in the head-up display can be seen as an addition to the information of the instrument cluster. Relevant driving information that is shown in current head-up displays are the driving speed, engine speed, navigation instructions, speed limit information, the status of the cruise control, or warning symbols.

Figure 6 Mercedes-Benz head-up display

The advantage of head-up displays is that reading the information does not require taking the eyes off the road. Therefore, the information can be perceived faster. However, the head-up display is not a substitute for the instrument cluster because it can only display limited information content in order to avoid an over-stimulation in the primary field of the driver´s view. The representation of the information shown in the head-up display can be static or contact analogue. A static representation shows relevant information at the same point of the driver´s field of view. In contrast to static head-up displays, contact analog displays show the information in a way that it merges with the reality, so that the driver has the feeling that the information are a part of the environment. Figure 7 exemplifies how navigation information could look like on a contact analog head-up display. However, the realization of contact analogue head-up displays requires a high degree of technical complexity. Until now, contact analog head-up displays are not available in any mass-production vehicle they rather are an object of research.

Figure 7 BMW Group conceptual contact analog head-up display

The third possible area for the display of advanced driver assistance systems is the display in the center console, which is used for the presentation of driver and co-driver relevant information. The central display includes the infotainment system that is mainly composed of the navigation system, car radio, telephone, vehicle settings, Internet, and driver assistance systems. A driver assistance system that is shown in the central display of the current Mercedes Benz C-Class model is the parking assistant. It supports the driver visually during parking and maneuvering, as shown in figure 8.

Figure 8 Mercedes-Benz C-Class active parking assist and 360° camera

2.6 Graphical Visualization of Advanced Driver Assistance Systems

Advanced driver assistance systems support, inform, and warn the driver about current driving situations. They even actively intervene in the vehicle control or take over specific driving tasks. Feedback about the actions of the driver assistance system is presented to the driver via graphical user interfaces as shown in figure 9-12.

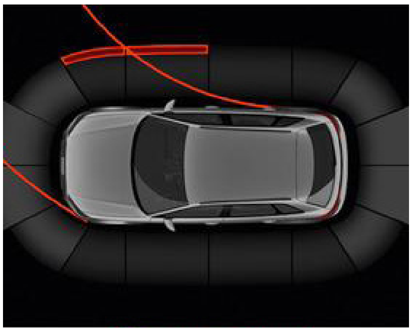


Figure 9 Audi parking aid

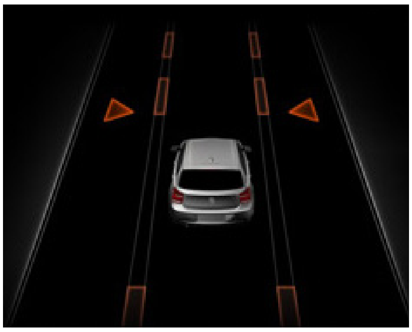


Figure 10 BMW lane departure warning

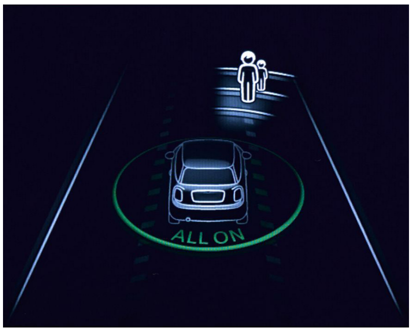


Figure 11 Mini pedestrian warning system

Figure 12 Mercedes-Benz active blind spot assistant

The graphical user interface shows the information collected by the sensors and the status of the system in a graphical representation. This graphical representation has the advantage that the complex sensor data are presented to the driver in a user friendly, attractive, and easy to interpret way. By comparing, for example, different graphical representations of the adaptive cruise control, it can be seen that the graphical user interface for the same function differs greatly in terms of detail (see figure 13).

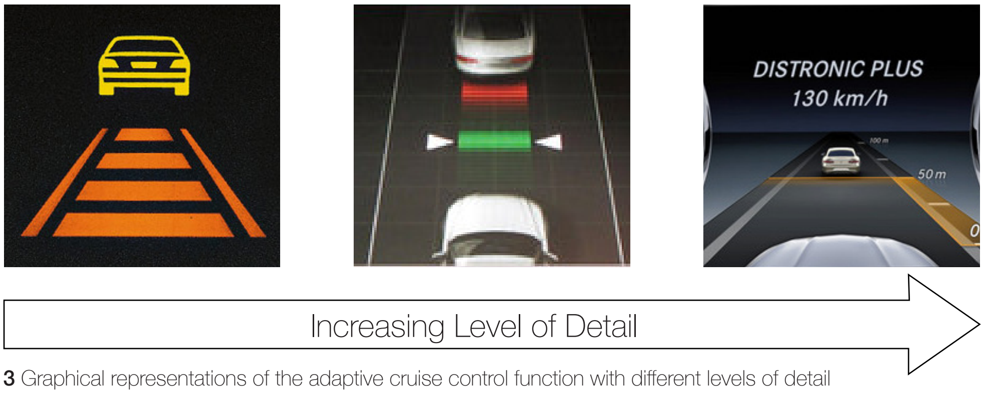


Figure 13 Graphical representations of the adaptive cruise control function with different levels of detail

Furthermore, it can be observed that the level of detail within the graphical user interface increases also with rising levels of driver assistance automation. Current graphical user interface concepts of Audi and Tesla for highly automated driving illustrate next to the ego-vehicle and the vehicle ahead, additionally the passing vehicles on the adjacent lanes (see figure 14,15). Therefore, the level of detail is an important aspect that needs to be considered during the graphical user interface design process. It is important to carefully examine what information the driver needs to know in order to comprehend the behavior of the system. On the one hand, the driver should not lose the confidence in the driver assistance system due to a lack of displayed information. On the other hand, the driver should not be confused and burdened by too much information of the driver assistance system.

Figure 14 Tesla graphical user interface concept for piloted driving

Figure 15 Audi graphical user interface concept for piloted driving

2.7 Influence of Advanced Driver Assistance Systems on the Driving Task

Advanced driver assistance systems support the driver and take over parts of the primary driving task. Therefore, they have an impact on the driver and the driving task. The taking over of the primary driving task by the assistance system helps to reduce the driver´s workload with the aim to increase traffic safety.[14] However, the interaction with an advanced driver assistance system also requires mental capacity. The reading and interpretation of the display information can lead to an additional mental workload, which counteracts the actual mental relief. With an increasing degree of the automation of advanced driver assistance system, the driving task changes from an active and regulating to a passive and monitoring task. The change of the driving task due to automated driver assistance systems can result in the loss of the driver´s situational awareness.

Situational awareness describes the "perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". [18] Due to the fact that advanced driver assistance systems monitor the traffic environment and take over specific driving tasks, the driver is not actively involved in all driving tasks anymore. According to a phenomenon known as the generation effect, people have a higher situational awareness if they are actively involved in the execution of tasks than when they are passive monitors of something. [19] The result of reduced situational awareness is that the driver is not immediately aware of the actions of the vehicle and the current and developing road traffic situation. The loss of situational awareness is problematic when the assistance system reaches its limit and the driver is forced to take over the driving task. An inadequate situational awareness of the traffic environment in such a moment could lead to an inappropriate estimation of the driving situation and to a wrong reaction of the driver. Therefore, it is important that advanced driver assistance systems support the driver´s situational awareness as long as the system is not able to operate completely autonomously.

With increasing levels of automation of driver assistance systems it is important that the driver understands the behavior and the mode of the system. This is referred to as mode awareness. Sarter & Woods define mode awareness as "the ability of a supervisor to track and to anticipate the behavior of automated systems". [20] For a sufficient level of mode awareness the driver needs to understand what the advanced driver assistance system is doing at a given moment, why it is doing so and what the system is going to do. Therefore, it is important that the driver has a sufficient mental model of the automated assistance system. The term mental model describes a person´s internal and personalized understanding of the way a device or system works. [21] A mental model of an automated system is mainly formed by system feedback to the user. [22] This means that the design of the graphical user interface is of great importance in order to support the driver to build up a mental model of the system and evaluate the behavior of the system properly at any time.

CHAPTER **3**

Methods for the Graphical User Interface Development

The goal of this assignment is to design an integrated graphical user interface for the semi-automated lane change assistant system that makes the interaction between user and system as simple and effective as possible. To reach this goal there are different methods and design guidelines that need to be considered during the design process. This chapter gives an overview of the methods and guidelines that are considered for the graphical user interface design process of the semi-automated lane change assistant system.

3.1 User Centered Design Process

Through the rising number of advanced driver assistance systems, the amount of information presented to the driver increases as well.The increasing amount of data can be overwhelming and decrease the driver´s ability to efficiently process the presented information. Therefore, the graphical user interface must be matched to the abilities and capabilities of the driver. During the development process there are four main questions that need to be answered [23]:

1. *What information should be display to the driver?*
2. *How should the information be present to the driver?*
3. *In which way should the information be organized?*
4. *What information should be emphasized?*

A process that helps to answer these questions and to develop effective user interfaces is user-centered design. User-centered design is a methodological process used to achieve user-friendly interfaces with a high level of usability. [24] It builds on the principle that the design is based on a comprehensive understanding of users, tasks, and the environment of use. Fundamentally, the user-centered design process is characterized by an iterative approach that consists of the following four phases:

1.Understand and specify the Use of Context

The analysis of the context of use is the first phase within the user-centered development process and builds the foundation for the whole process. During this phase, the system, the intended users of the system, the environment of use, and the tasks the system is used for, are analyzed.

2.Specifying Usage Requirements

The development of requirements is the next step in the user-centered design process. In this phase the usability goals of the system are set based on the previous analysis. Furthermore, the specification of design guidelines, constrains, and other requirements are included.

3.Develop Design Solutions

In this phase of the user-centered design process, design solutions are developed. Different kinds of prototypes (Sketches, Mock-Ups, Animations) are used to make ideas visible and understandable.

4.Evaluate Design Solutions

In the fourth phase, the design solutions are evaluated against established requirements. This activity is closely coupled with the creation of design solutions and should occur in all stages of the system life cycle.

For each phase of the user-centered design process, different methods can be used. Figure 16 shows the different phases in combination with the chosen methods for the graphical user interface design process of the semi-automated lane change assistance system.

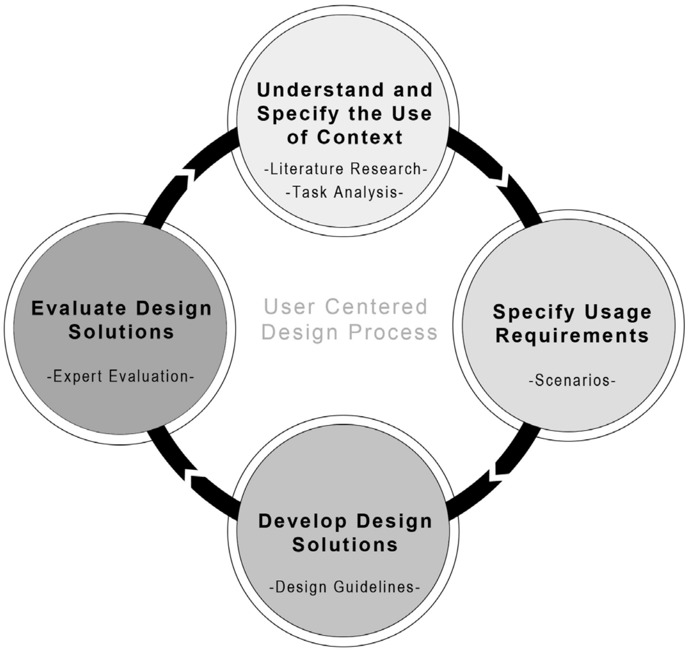


Figure 16 Chosen methods for the user centered design process

To understand and specify the use of context a literature research is done. The literature research forms the basis for the design process in order to build up a consolidated knowledge about advanced driver assistance system as well as the semi-automated lane change assistant. For the specification of usage requirements, different semi-automated lane change scenarios are described to consider possible situations that can occur during the usage.
To develop graphical user interface design solutions that are suitable for the driver, different design guidelines and standards are considered. Furthermore, animations are used for a clear visualization of the graphical user interface concepts. For the evaluation of the different concepts, a formative, expert-orientated evaluation is chosen in order to find weak points and chose the concept with the most potential.

3.2 Design Standards and Principles

The control and display systems in a vehicle should be designed to be suitable for the driver. Therefore, human capabilities must be taken into account during the entire design process. The semi-automated lane change assistant is a system that generates complex information. Some of that information must be presented to the driver in order to inform about the actions and the status of the system. The information that is presented on the display must be shown in a way that it supports the driver´s perception, situational awareness, and understanding. International design standards and guidelines provide guidance for a successful development of human machine interfaces. The following section gives a short description of the different available standards and guidelines for the design of human-machine interfaces. These range from car specific to general guidelines for the design of user-friendly interfaces.

3.2.1 European Statements of Principles (ESoP)

The European Statements of Principles contain 35 principles for the interface design of in-vehicle information and communication systems. [25] The overall aim is to support the development of in-vehicle information and communication systems that do not distract or overload the driver while executing the driving task. Usually, the guidelines have been restricted to driver information systems. However, most of the principles can also be used for the development of driver assistance systems. [26] The 35 principles are divided into the following categories: overall design, installation, information presentation, interaction with displays and controls, system behavior, and information about the system. Relevant categories for the design of the graphical user interface of the semi-automated lane change assistant are the sections “Information presentation“, “System behavior”, and “Information about the system”. The complete list of principles is presented in appendix A.

3.2.2 ISO Standard 9241-12

The ISO-9241 is a multi-part international standard that describes the interaction between humans and computers. [27] The series of standards provides recommendations and requirements relating to hardware, software and the working environment. The aim of this standard is to develop ergonomic human machine interactions that contribute to a user-friendly system. An important part for the graphical user interface development within this assignment is the ISO standard 9241-12. The ISO 9241-12 contains specific principles for presenting information on visual displays. The principles are based on findings from psychology, ergonomics, typography, and graphic design. The standard describes seven principles for the presentation of information on visual displays. The list of principles can be found in appendix B.

3.2.3 General Interface Design Guidelines

In addition to the European Statements of Principles and the ISO-9241 standard, there are numerous general guidelines for the design of human machine interfaces. The guidelines consider, amongst others, the use of fonts, colors and the arrangement of information. A good overview of important guidelines for the design of graphical user interfaces is given by the 13 principles of display design defined by Wickens. [19] These principles help to develop effective displays that support the perception of relevant system variables and facilitate the processing of that information. The principles are categorized into perceptual, mental model, attention, and memory principles. An overview of the 13 Principles of display design is presented in appendix C.

CHAPTER 4

Semi-Automated Lane Change Assistant

This chapter describes the semi-automated lane change assistant. In order to comprehend how the semi-automated lane change system changes the driving task, the tasks a driver performs during a non-automated lane change are specified. Furthermore, to facilitate a clear understanding of the system, the preconditions and the functionality of the semi-automated lane change assistant are outlined. Finally, this chapter describes and analyses the current graphical user interface concept of the semi-automated lane change assistant.

4.1 The Lane Change

A lane change is a driving maneuver where a vehicle moves from one lane to another. [5] To execute a lane change, there must be two lanes with the same direction of travel. The lane change maneuver can be classified by its direction and essentiality. The direction of a lane change can be distinguished in a lane change to the left or to the right side. Concerning the essentiality of a lane change, a distinction can be made between essential and nonessential lane changes. Essential lane changes are caused by lane drop, lane closure or due to the fact that the driver wants to maintain a route. Nonessential lane changes are, for example, executed to avoid slow moving vehicles. In general, the lane change is a demanding driving task due to the fact that the driver needs to observe and control the front, rear, and side of the vehicle. [1] Furthermore, the driver needs to judge the speed of approaching and overtaking vehicles. For those reasons, the lane change is a driving task with a high potential for error. It is estimated that lane change crashes account for 4 to 10 percent of all vehicle crashes. [5]

4.1.1 Driving Task Lane Change

There are different models that describe the tasks a driver performs during a lane change maneuver. [28] The model developed by Chovan et al. gives a good and clear overview of the different steps of an ideal lane change behavior (see figure 17). [29] It describes the mental and physical tasks that a driver executes during a lane change maneuver.

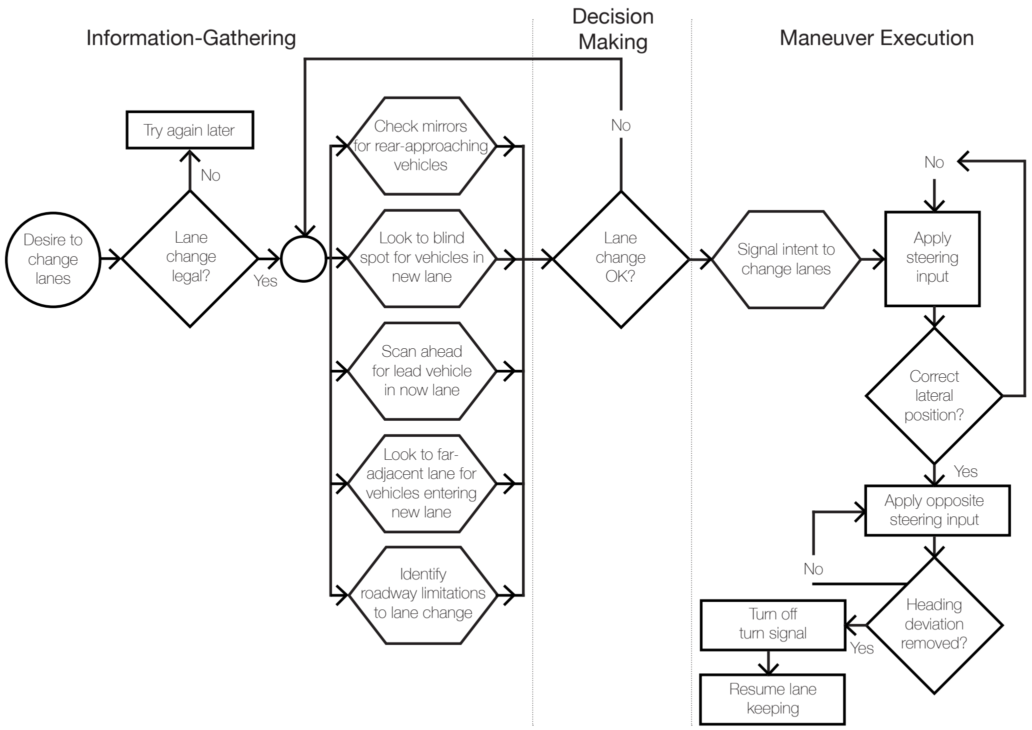


Figure 17 Ideal lane change behavior model

Overall, the model divides the lane change process into three major phases. The first phase is the information gathering process. In this phase the driver develops the desire to change lanes. In order to decide whether the desire to change lanes is legal, the driver begins to scan the traffic signs, signals and pavement markings. If the lane change is legal, the driver checks the mirrors to detect approaching vehicles, checks the blind spot, and scans the target lane to detect lead vehicles. On highways with more than two lanes, the driver additionally looks to the far-adjacent lane to see if a vehicle moves into the destination lane. Furthermore, the driver identifies the roadway for possible limitations during the lane change, such as intersections, cross-walks, narrow points, and so forth. The second phase of the lane change model is the decision making process. Depending on the gathered information of the previous phase, the driver decides whether a lane change is possible or not. If the driver decides that all conditions for a successful lane change are met, he begins to execute the lane change maneuver. The execution of the lane change maneuver is the third phase of the lane change model. The first driver task within the execution phase is the indication of the upcoming lane change, by using the turn indicator. Afterwards, the driver applies a steering input to guide the vehicle to the destination lane. As soon as the vehicle reaches the destination lane, the driver applies a steering input in the opposite direction to stabilize the vehicle. Finally, in the third phase of the lane change maneuver, the driver turns off the turn signal and resumes lane keeping.

4.2 Semi-Automated Lane Change Assistant

A lane change assistant is an advanced driver assistance system that supports the driver to change lanes safely. Current lane change assistance systems scan the environment around the vehicle and warn the driver at different stages of impending collisions before and during a lane change. Most lane change assistant systems make use of a warning signal positioned in the exterior mirrors and in the instrument cluster to indicate whether a lane change is possible or not, as shown in figure 18.

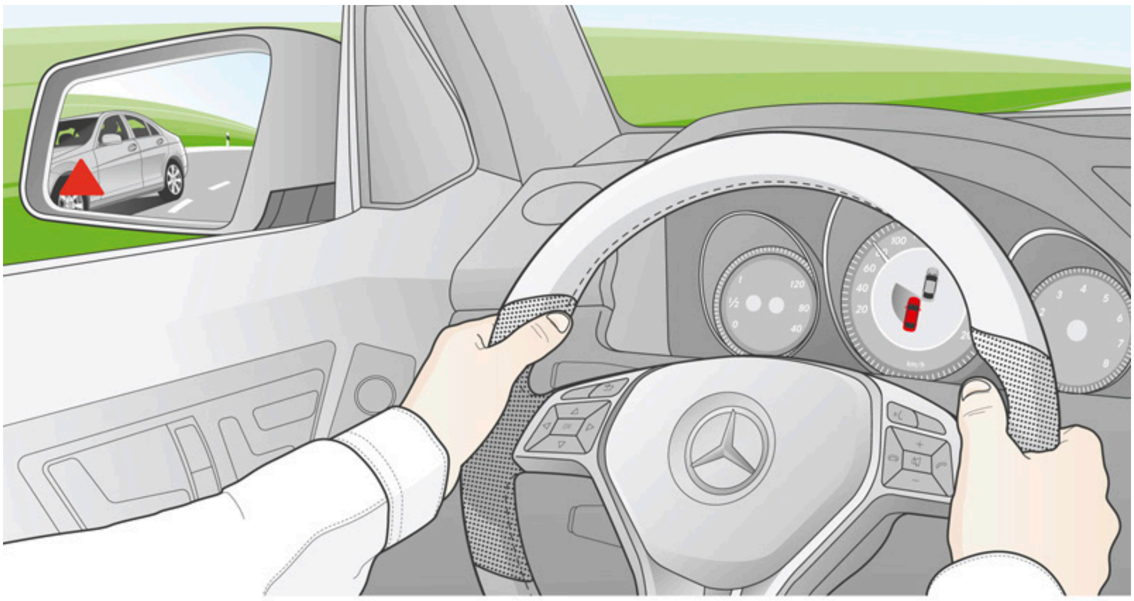


Figure 18 Mercedes-Benz active blind spot assistant

The semi-automated lane change assistant differs from current lane change assistant systems by performing the lane change maneuver automatically after initiation by the driver. Therefore, the semi-automated lane change assistant executes all tasks, despite the desire to change lanes. This has the consequence that the driver´s task changes from an active and regulating to a passive and monitoring task. As mentioned above, this changing role of the driver´s function can result in the loss of the situational and mode awareness. However, since it is a semi-automated driver assistance system, the driver still has the duty to monitor the traffic environment while the system performs the lane change.

The semi-automated lane change assistant, currently developed by the Daimler AG, builds up on the advanced driver assistance system DISTRONIC Plus with steering assistant. DISTRONIC Plus is an adaptive cruise control assistance system that regulates the speed and adjusts it to keep a set distance to a preceding vehicle. DISTRONIC Plus is enabled and operated by the driver through an control element that is located below the turn indicator, as shown in figure 19.

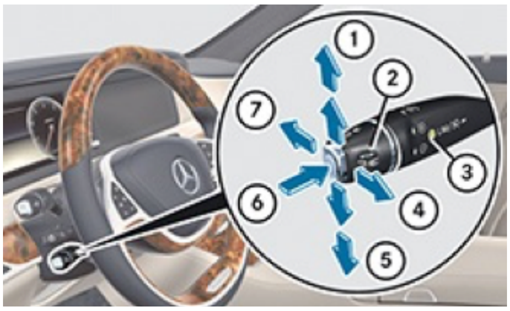


Figure 19 Control element DISTRONIC Plus

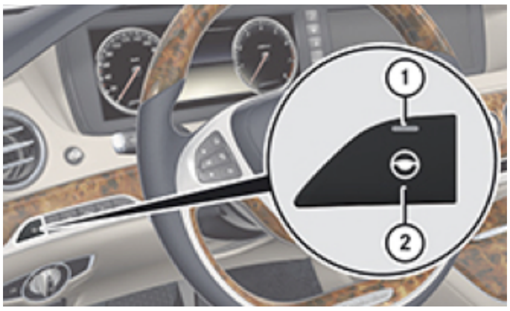


Figure 20 On-off switch steering assistant

By operating the control element, the distance to the vehicle ahead as well as the speed can be adjusted at any time during driving. The steering assistant supports the driver in the transverse guidance of the vehicle through moderate steering adjustments to keep the vehicle in the center of the lane. To activate the steering assistant in the current Mercedes Benz S-Class model, the driver needs to press the steering assistant button that is located in the driver assistance bar next to the steering wheel (see figure 20). The display of the DISTRONIC Plus and the steering assistant is located in the instrument cluster. It is divided into an indicator in the speedometer and the driver assistance graphic. A triangle in the speedometer shows the driver the set speed (see figure 21, number 2). If the sensors of the DISTRONIC Plus recognize a preceding vehicle, the difference between the set speed and the speed of the vehicle ahead is shown in the speedometer by an orange line (see figure 21, number 1).

Figure 21 DISTRONIC Plus elements in the speedometer

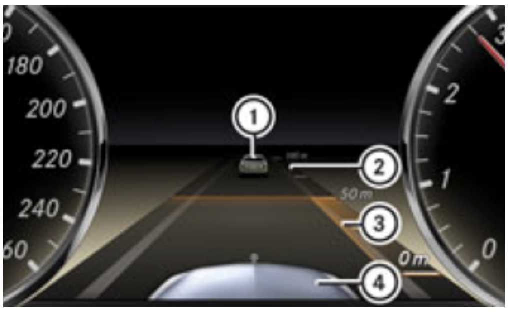


Figure 22 DISTRONIC Plus driver assistance graphic

The driver assistance graphic shows the distance between the ego-vehicle (figure 22, number 4) and a detected preceding vehicle (figure 22, number 1). In addition, the set target distance to a vehicle ahead is indicated by an orange line (figure 22, number 3). Furthermore, the driver assistance graphic provides textual feedback on the activity of the DISTRONIC Plus. The availability of the steering assistant is displayed via an icon. The icon is located in the status bar below the driver assistance graphic (see figure 23, number 1). When the steering assistant is turned on but not available, a gray steering wheel icon appears in the status bar. As soon as the steering assistant is available, the icon changes form gray to green.

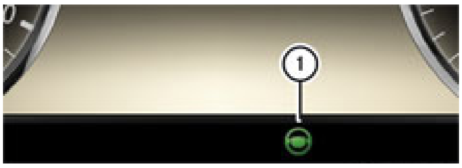


Figure 23 Steering assistant icon in the status bar

As a prerequisite for the use of the semi-automated lane change assistant, DISTRONIC Plus must be turned on and the steering assistant must be available. Additionally, the semi-automated lane change assistant is only available on structural separated streets with two or more lanes. If these conditions are met, the driver can request the semi-automated lane change. The triggering of the function is carried out with a suitable control element, such as a modified turn indicator or additional controls located near to the steering wheel. The exact definition of the control element for the semi-automated lane change assistant is not the subject of this assignment. The focus of this thesis is on the development of the graphical user interface. When the driver has requested the semi-automated lane change, the system searches for a suitable gap on the target lane and executes the lane change autonomously if a gap is found. During the search as well as the execution phase, the driver can override the system to take over the lead of the vehicle.

The following table gives an overview of the distribution of tasks between the driver, the system, and the interface of the semi-automated lane change assistant. The interface can be seen as the mediating part between driver and semi-automated lane change assistance system.

	Driver	**Interface**	**System**
Pre-condition	Turn DISTRONIC Plus on	Feedback: DISTRONIC Plus active/passive Display the set speed Display the set distance to the vehicle ahead	Detect vehicles ahead Regulate distance Regulate speed
	Turn Steering Assistant on	Feedback: Steering Assist active/passive	Detect lane marking Support the driver in the transverse control of the vehicle
	Turn Lane Change Assistant on	Feedback: Lane Change Assistant active/passive	Check if lane change is possible/allowed

Triggering Event Lane Change	Request lane change	Feedback: Lane change desire detected	Detect the lane change desire from the actual lane to the target lane
Function Sequence Lane Change		Feedback: System searches for a suitable gap to change lanes	Detect vehicles on target lane and search for a suitable gap on the target lane
		Feedback: System has found a suitable gap and begins to execute the lane change	Execute the lane change maneuver when a suitable gap is found
		Feedback: Lane change maneuver is finished	Finish the lane change maneuver
Termination Condition Lane Change	Take over the driving task after takeover request by the system	Feedback: Lane change not possible anymore Depending on the situation notify driver to takeover	Successful lane change not possible
	Intervene during the automated lane change maneuver	Feedback: Intervention detected	Stop automated lane change maneuver

Table 1 Distribution of tasks between the driver, system, and interface

4.3 The Current Graphical User Interface Concept

Previously to this bachelor assignment, different concepts for the graphical user interface of the semi-automated lane change assistance system have been generated and evaluated by the Daimler AG. In this section, the current graphical user interface concept of the semi-automated lane change assistant system is described. This forms the basis for the further development of this study. The current concept uses the instrument cluster as display location for the graphical user interface due to the fact that it offers enough space to display all elements of the semi-automated lane change assistant system in a clear and understandable manner. The graphical elements are positioned in the middle of the instrument cluster between the speed indicator and the revolution counter. For the reason that lane changes are often executed to maintain a route, lane change suggestions based on navigational data are integrated into the graphical user interface as well. The interface is divided into three main areas, as depicted in figure 24. The upper display area shows the available lanes of the current road section. The lane on which the ego-vehicle is located, is displayed directly in front of it. A difference in brightness of the shown lanes indicates the recommended lane according to the navigational information. The ideal lane corresponding to the route guidance is displayed in a brighter hue to be easily distinguishable from the other lanes.

In the central area of the graphical user interface the ego-vehicle is displayed surrounded by a ring. The ring around the ego-vehicle is used as a metaphorical element and abstracts the 360° view of the sensors around the car. The coloring of the ring element is used as feedback for the system activity. If the driver requests the semi-automated lane change, a yellow ring indicates that the system searches for a gap on the target lane because an automated lane change is not immediately possible. Once the system has found a gap on the target lane, the color of the ring changes from yellow to green to symbolize that the semi-automated lane change maneuver begins. Furthermore, there is a distinction between the coloring of the left and right side. Depending on whether the driver requests a semi-automated lane change to the right or to the left, the corresponding ring side is colored. This feature serves as feedback in order to show the driver to which side the semi-automated lane change has been requested. In the lower area of the graphical user interface an status icon shows the availability of the semi-automated lane change assistance system. A green icon indicates that the system is available. As soon as the semi-automated lane change assistance system is inactive, the color of the icon changes from green to gray.

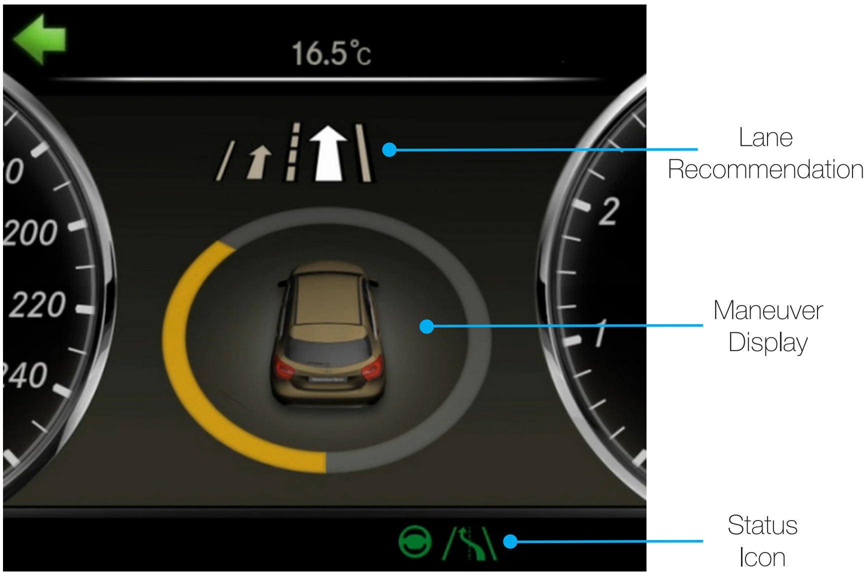


Figure 24 Current semi-automated lane change graphical user interface concept

The current graphical user interface concept as described above, considers the semi-automated lane change assistant separate from other advanced driver assistance systems. In order to minimize the driver´s mental capacity, which is needed to understand and interpret information of different driver assistance systems, they should be integrated into one graphical user interface. Ideally, the information of several driver assistance systems should be presented in one integrated and clearly arranged, easy to understand graphical user interface. A useful extension of the current concept is therefore the combination with other advanced driver assistance systems. Suitable systems for the combination with the semi-automated lane change assistant are the DISTRONIC Plus and the steering assistant. These systems are suitable because they have to be active as a precondition for the availability of semi-automated lane change assistant. Furthermore, the current concept has the potential for a better and clearer integration of lane change recommendations based on navigation information. Due to a clear and early indication of the target lane, the driver can request the semi-automated lane change on time.

CHAPTER 5
Graphical User Interface Requirements Analysis

In this chapter, the graphical user interface requirements for the semi-automated lane change assistance system are further determined. Next to the general design principles for visual displays, described in chapter three, this chapter considers different lane change scenarios in order to design a suitable interface for the semi-automated lane change assistant. Furthermore, the user group and their demands on the graphical user interface are considered in this chapter. The collected demands are finally summarized in a list of requirements. This list serves as the basis for the subsequent concept generation.

5.1 Semi-Automated Lane Change Scenarios

In section 4.1 the lane change and the associated driving task have already been analyzed in general. However, a lane change is a dynamic driving maneuver that can be affected by a variety of environmental influences, such as the road and traffic management, traffic density, and the behavior of other road users. Furthermore, the use of a semi-automated lane change assistant leads to the change of the driver's task from an executing to a supervisory task. In order to understand the system`s activities in different lane change situations, the graphical user interface must provide the driver with information that are suitable in a given situation. With the help of various lane change scenarios, it is analyzed, which information the interface should present to the driver during the automated lane change process. For a better categorization of the different scenarios that may occur during a semi-automated lane change, the process is divided into three phases. The first phase is the request phase in which the driver requests the semi-automated lane change. The second phase is the search phase, where the system searches for a suitable gap on the target lane. The third phase is the execution phase, in which the system performs the semi-automated lane change. The following section describes possible scenarios that can occur in each of the three phases. In all scenarios it is assumed that the conditions for the availability of the semi-automated lane change are met at the moment when the driver requests the lane change.

5.1.1 Possible scenarios during the request of the semi-automated lane change

Scenario "Free target lane"

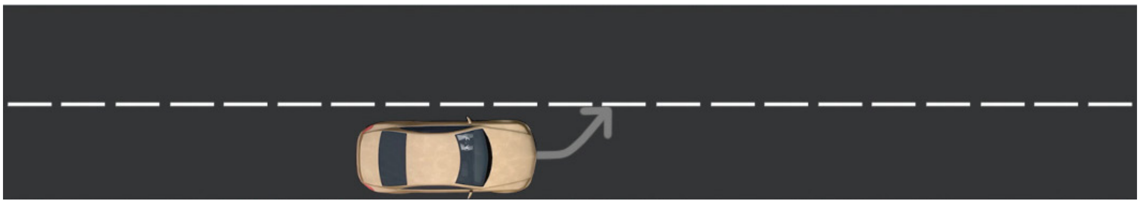


Figure 25 Scenario "Free target lane"

The scenario "Free target lane" outlines a situation without vehicles on the target lane when the driver requests the semi-automated lane change. Due to the fact that the sensors of the car monitor the traffic environment permanently, the semi-automated lane change can be executed immediately after the request of the driver. Therefore, the driver should be informed via the graphical user interface that the semi-automated lane change is immediately executed.

Scenario "Vehicle on target lane"

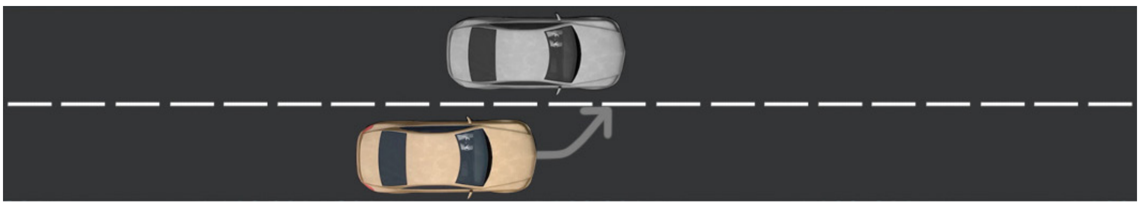


Figure 26 Scenario "Vehicle on target lane"

The scenario "Vehicle on target lane" describes a situation in which a vehicle is located on the target lane when the driver requests the semi-automated lane change. Accordingly, it is not possible for the system to execute the lane change directly. In this situation, the system has to search for a suitable gap on the target lane prior to the execution of the lane change. Thus, the graphical user interface should inform the driver that the system searches for a gap on the target lane because an immediate lane change is not possible.

5.1.2 Possible scenarios during the search phase of the semi-automated lane change

Scenario "Blocked target lane"

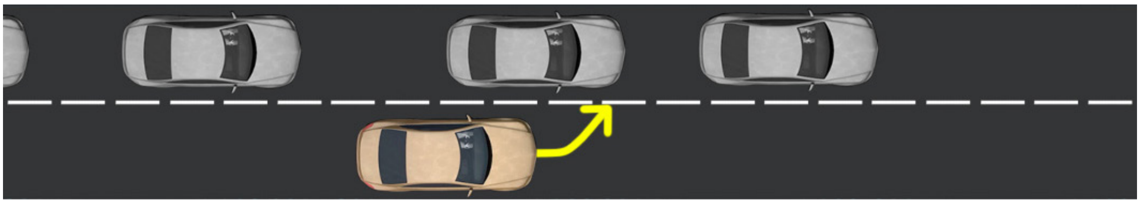


Figure 27 Scenario "Blocked target lane"

The scenario "Blocked target lane" specifies a situation where the traffic volume on the target lane is too high to execute the semi-automated lane change. If the system cannot perform the lane change within a given time range, the search phase should be canceled. This prevents the possibility that the system runs further in the background without being noticed by the driver. The exact space of time until the search phase should be canceled must be further examined. However, the graphical user interface must clearly indicate to the driver when the search phase is canceled.

Scenario "Ending lane"

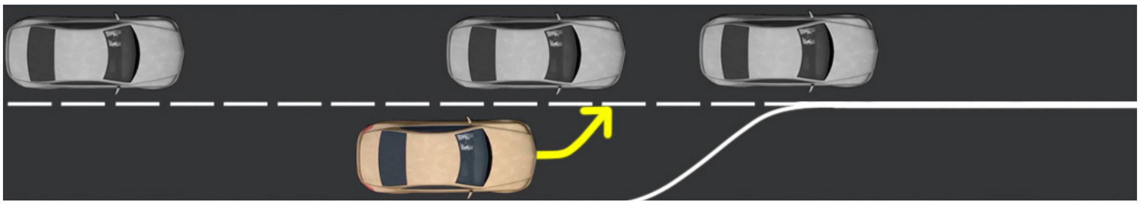


Figure 28 Scenario "Ending lane"

The scenario "Ending lane" describes a driving situation in which the semi-automated lane change assistant is not able to find a suitable gap on the target lane while the layout of the road changes from two lanes to one lane. Due to the fact that the lane change assistant is a semi-automated assistance system, the driver has the task to actively monitor the driving environment and intervene if necessary. Therefore, the driver should realize the ending lane and actively intervene if it is not possible for the system to execute the lane change. However, if the system knows the layout of the street and the actual position of the car, the driver could be informed, at a given moment, that the lane change must be executed manually. In this situation, the graphical user interface should clearly indicate when the search phase is canceled. Since the course of the road is not always good to foresee by the driver, it is important that the abortion of the semi-automated lane change is comprehensible for the driver.

Scenario "Lane change not allowed anymore"

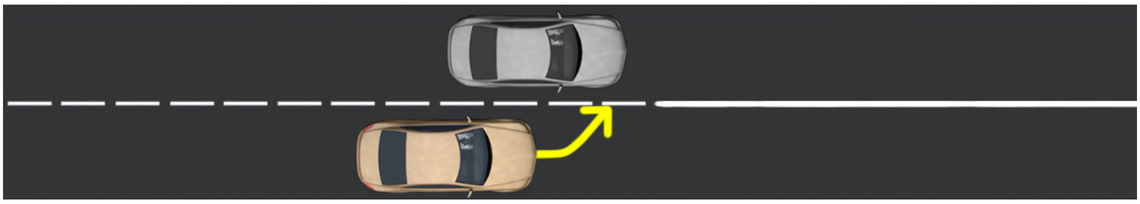


Figure 29 Scenario "Lane change not allowed anymore"

The scenario "Lane change not allowed anymore" defines a situation where the traffic conditions change during the search phase, so that the semi-automated lane change assistant is no longer available. An example of this scenario is the change of the lane marking from a dashed to a solid line. If it is not possible for the system to execute the automated lane change before the beginning of the solid line, the search phase is canceled. However, this situation is not as critical as the scenario "Ending Lane" because the vehicle can keep on driving on the current lane. Therefore, it is not absolutely necessary to inform the driver about the upcoming situation. Anyway, it should be clear for the driver when the search phase is canceled and the semi-automated lane change assistant is unavailable.

5.1.3 Possible scenarios during the execution phase of the semi-automated lane change

Scenario "Fast vehicle on target lane"

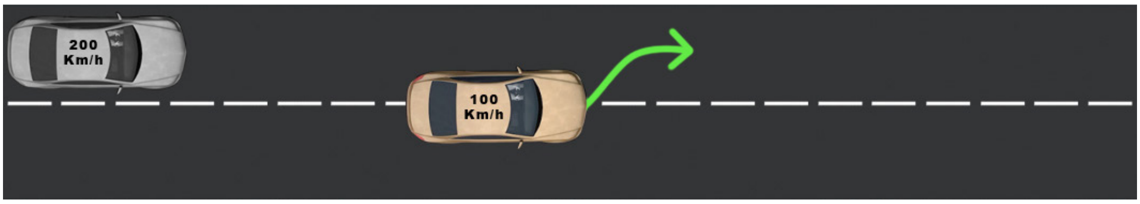


Figure 30 Scenario "Fast vehicle on target lane"

The scenario "Fast vehicle on target lane" illustrates a situation in which a vehicle is approaching on the target lane at a high speed, while the semi-automated lane change maneuver is executed. Since the driver has the task to actively monitor the driving environment before and during the semi-automated lane change, the approaching vehicle should be noticed. Therefore, the driver should actively intervene to guide the vehicle back to the starting lane. However, if the approaching vehicle is not detected by the driver, an acoustic warning and a visual signal in the side mirror is generated by the active blind spot assist. Additionally, the blind spot assist takes evasive action in the event of danger. In this situation, the semi-automated lane change maneuver should be interrupted as soon as the active blind spot assistant detects an approaching vehicle. This means for the design of the graphical user interface, that it must indicate the abortion of the semi-automated lane change maneuver to the driver clearly.

Scenario "Simultaneous lane change"

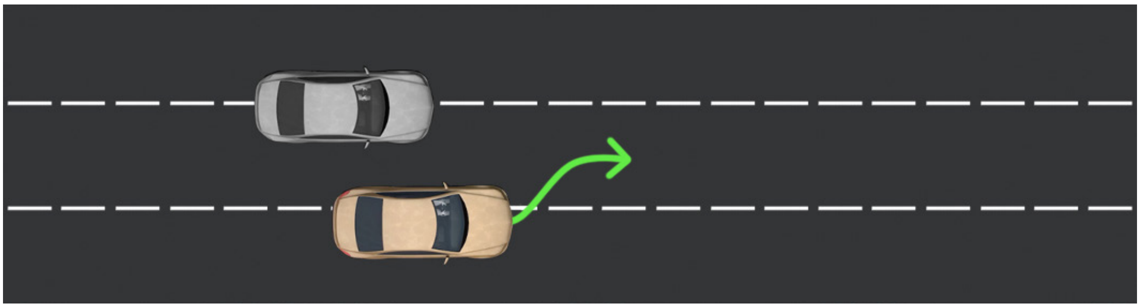


Figure 31 Scenario "Simultaneous lane change"

The scenario "Simultaneous lane change" describes a situation in which the semi-automated lane change assist and another vehicle execute the lane change simultaneously to the same target lane. This situation is comparable to the scenario outlined above because the driver should monitor the driving environment actively while driving semi-automated. Thus, the approaching vehicle from the far-adjacent lane should be noticed by the driver and lead to an active intervention. If the driver does not detect the approaching vehicle, the blind spot assist warns the driver in this situation visually, acoustically, and even evades the approaching vehicle. As soon as the active blind spot assistant detects a vehicle, the semi-automated lane change assistant should be deactivated in order to interrupt the maneuver. The deactivation of the semi-automated lane change assistant and the termination of the maneuver should be clearly and noticeable indicated by the graphical user interface.

5.2 User Group of the Semi-Automated Lane Change Assistant

The user of the semi-automated lane change assistant is the driver. However, drivers are an extremely heterogeneous group of users. They differ from one another in terms of age, driving experience, frequency of vehicle use, life situation, mental abilities, experience with computer technologies, and in the readiness to take risk. [30] For this reason, it is not possible to identify specific characteristics of the user group. Common characteristics of the user group can only be identified on a general level. A general property is the possession of a driver´s license. This requires a minimum age and a certain level of education such as the ability to read and write. No matter which specific characteristics single users have, it is important that the graphical user interface for the semi-automated lane change assistant is designed in a way that the wide target audience can easily understand, interpret and use it. Furthermore, it can be assumed that not all drivers use the semi-automated lane change assistant permanently. Systems that are only used occasionally should be designed in a way that they are attractive, motivating, and easy to use. [31]

5.3 List of Requirements

In this section, the collected graphical user interface demands for the semi-automated lane change assistant are summarized in a list of requirements. Those will be used as guidance for the further design process. The following list shows the requirements that the final graphical user interface has to fulfill.

- The graphical user interface integrates the elements of the current semi-automated lane change assistant concept, the DISTRONIC Plus and the steering assistant
- The graphical user interface clearly indicates when the semi-automated lane change assistant system is active or passive in order to support the driver´s mode awareness
- The graphical user interface shows the driver in which operating phase the semi-automated lane change assistant is in order to support the driver´s mode awareness
- The graphical user interface supports the driver´s situational awareness and directs it to the areas that need to be monitored during the semi-automated lane change maneuver
- The graphical user interface uses the color yellow in order to indicate that the system searches for a suitable gap on the target lane
- The graphical user interface uses the color green in order to indicate that the system executes the semi-automated lane change
- The graphical user interface indicates an abortion of the semi-automated lane change in the search or in the execution phase clearly and comprehensible for the driver
- The graphical user interface can easily be understood by the heterogeneous user group
- The graphical user interface considers the guidelines and standards for the design of visual displays

CHAPTER **6**

Concept Development of the Graphical User Interface

This chapter describes the development process of three different graphical user interface concepts for the semi-automated lane change assistant. The list of requirements defined in the previous chapter and the current graphical user interface concept serve as a basis for the concept development in this chapter. There are two main goals for the design of the graphical user interface. On the one hand, it should support the driver´s understanding of the behavior and mode of the system. On the other hand, the graphical user interface should be designed in order to encourage the driver´s situational awareness. Based on the previous analysis, ideas for the further development of the graphical user interface for the semi-automated lane change assistant system are generated. The final section of this chapter describes the working principle and illustrates the layout of the three graphical user interface concepts of the semi-automated lane change assistance system.

6.1 Ideation

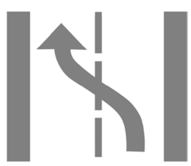
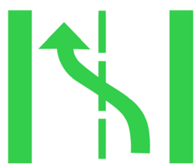
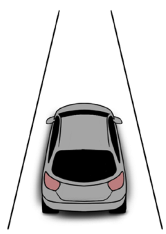
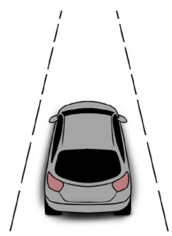
In the ideation phase, as many ideas as possible are generated for the design of the graphical user interface of the semi-automated lane change assistant. In the first step of the ideation phase important graphical user interface criteria are defined based on the list of requirements and the current interface concept. Afterwards, possible design solutions are explored separately for each criterion. The generated ideas with the highest potential serve as basis for the conceptualization phase, which is the next step in the graphical user interface design process.

6.1.1Graphical User Interface Design Criteria and Possible Design Solutions

In this section, different important visualization criteria for the development of the graphical user interface of the semi-automated lane change assistant are presented in combination with possible design solutions.

Criterion 1: Availability of the semi-automated lane change assistant

The first visualization criterion considers the illustration of the availability of the semi-automated lane change assistant. In order to support the driver´s mode awareness it should be clearly indicated when the assistant is available or unavailable. The display of the current mode should be salient enough to be perceived by the driver. However, it should not be obtrusive in order to minimize the visual workload on the driver. The following table illustrates different ideas how to indicate the mode of the system.

Design Solution	Illustration	
	Not available (Passive)	Available (Active)
Color change of a status icon		
Change of the lane marking		

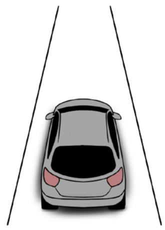
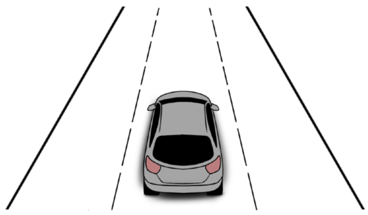
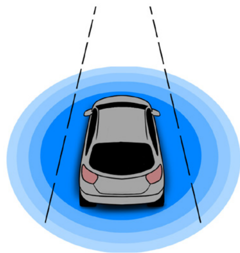
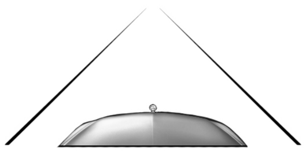
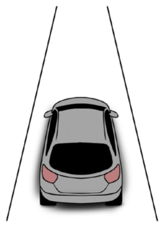
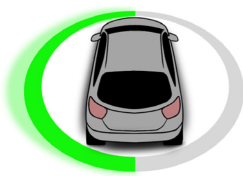
Fade in possible lanes for a lane change		
Area around ego-vehicle that indicates driver assistance in longitudinal and transverse direction		
Change of the ego-vehicle´s perspective		

Table 2 Design solutions for the illustration of the availability of the semi-automated lane change assistant system

Criterion 2: Visualization of the search and execution phase

In order to inform the driver about the current status of the semi-automated lane change maneuver, the second visualization criterion deals with the illustration of the search and execution phase. Next to the ring depiction, which is used in the current graphical user interface concept, additional ideas are generated. The following table gives an overview of different ideas how to inform the driver about the search and execution phase of the semi-automated lane change maneuver.

Design Solution	Illustration	
	Search Phase	Execution Phase
Ring around ego-vehicle		

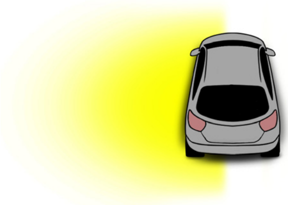
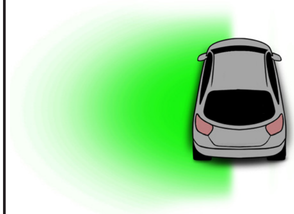
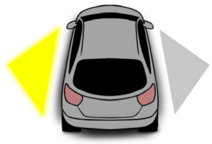
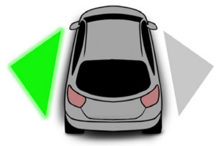
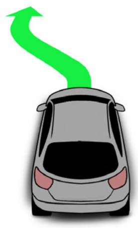
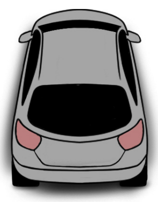
Area next to ego-vehicle		
Triangle next to ego-vehicle		
Arrow in front of ego-vehicle		

Table 3 Design solutions for the visualization of the search and execution phase of the semi-automated lane change maneuver

Criterion 3: Visualization of the ego-vehicle

The third visualization criterion considers the display of the ego-vehicle. The illustration of the ego-vehicle is an important criterion because it defines significantly the possibilities for the depiction of the scene around it. A hood view perspective, for example, makes it impossible to inform the driver via the graphical user interface about occurrences that happen behind or next to the vehicle. However, a top-view perspective makes it more difficult to accurately illustrate the distance to a detected vehicle ahead. The following table shows different possibilities to present the ego-vehicle in the graphical user interface.

Design Solution	Illustration
Hood View	
Rear View	

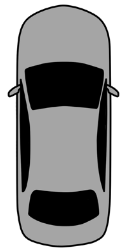
Top View	

Table 4 Design solutions for the visualization of the ego-vehicle

Criterion 4: Visualization of the vehicle ahead

The fourth visualization criterion considers the illustration of the vehicle ahead. Due to the fact that similar elements in a graphical user interface can cause confusion, the ego-vehicle and the vehicle ahead should be clearly distinguishable from each other. The following table outlines different possibilities how to illustrate the vehicle ahead.

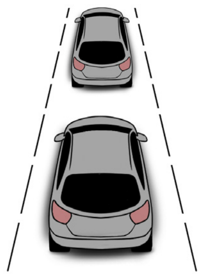
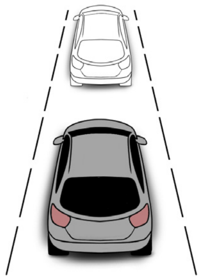
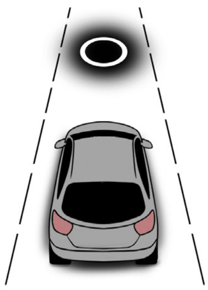
Design Solution	Illustration
Detailed illustration	
Wireframe illustration	
Abstract illustration	

Table 5 Design solutions for the illustration of the vehicle ahead

Criterion 5: Visualization of the traffic on the target lane

The fifth visualization criterion deals with the representation of the detected vehicles on the target lane. Due to the fact that the vehicle ahead is displayed in the graphical user interface, it could also be considered to illustrate the passing vehicles on the lanes next to the ego-vehicle. The following table outlines possible solutions for the illustration of the passing vehicles.

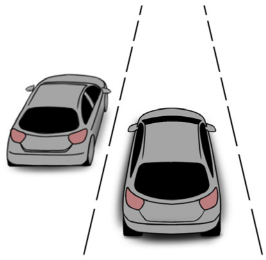
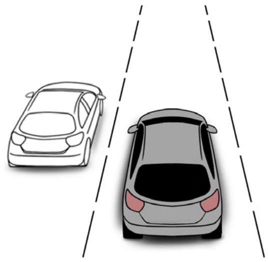
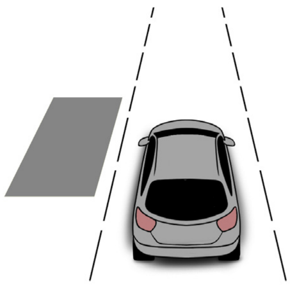
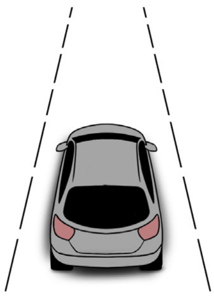
Design Solution	Illustration
Detailed illustration	
Wireframe illustration	
Abstract illustration	
No illustration of vehicles on the target lane	

Table 6 Design solutions for the visualization of the traffic on the target lane

Criterion 6: Visualization of the street lanes

The sixth criterion for the visualization of the semi-automated lane change assistant considers the illustration of the street lanes in the graphical user interface. Different possibilities for the graphical representation of the street lanes are outlines in the following table.

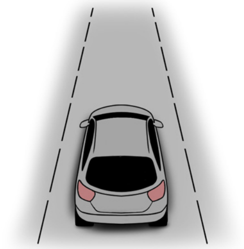
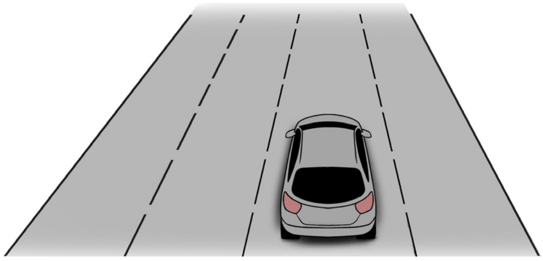
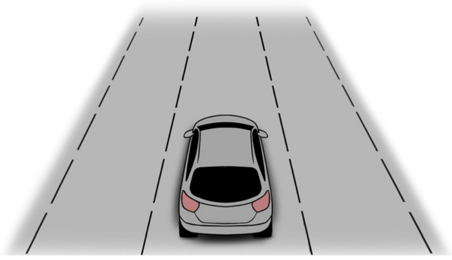
Design Solution	Illustration
Display only a single lane	
Display all accessible lanes	
Display only the right and left lane next to the ego-lane	

Table 7 Design solutions for the illustration of the street lanes

Criterion 7: Visualization of lane change recommendations

An additional feature of the semi-automated lane change assistant is to inform the driver about upcoming lane changes in order to follow the recommended route provided by the navigation system. Possible graphical solutions are presented in the following table.

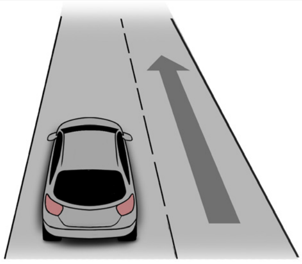
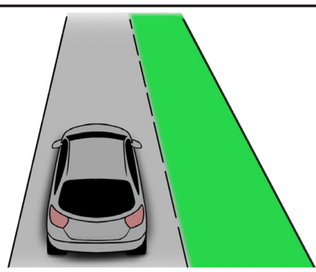
Design Solution	Illustration
Indicate target lane by arrow	
Indicate target lane by color	

Table 8 Design solutions for the illustration of lane change recommendations

6.2 Display Location

The chosen display location for the graphical user interface concepts is the instrument cluster. The advantage of the instrument cluster over the head up display is that it offers enough space for the integrated graphical user interface of the semi-automated lane change assistant, DISTRONIC Plus and the steering assistant. In comparison to the display in the center console, the instrument cluster has the benefit that the information generated by the semi-automated lane change assistance system are presented at the edge of the primary field of the driver´s view and can therefore be faster perceived.

6.3 Conceptualization

The ideas presented in the previous section have been discussed and evaluated with interface experts of the Daimler AG. Based on these discussions, various ideas have been prioritized for the further development. The generated and evaluated ideas result in three graphical user interface concepts that are described in this section.
For the illustration of the function of the graphical user interfaces, a video prototype has been created for each concept. The three video prototypes are tuned to a filmed usage scenario in order to clarify what the graphical user interfaces display at specific driving situations. To compare the three concepts they are adjusted to the same usage scenario. The concept animations are created with the program Adope After Effects and can be found on the accompanying DVD.

6.3.1 Concept “Change of Perspective”

The concept “change of perspective” is based on the current graphical user interface of the DISTRONIC Plus. The visual display of the DISTRONIC Plus embodies a high degree of realism, as depicted in figure 32. It shows in a perspective view, from an elevation angle of about 15°, the hood of the ego-vehicle and the road in front it. Preceding vehicles are illustrated in the graphical user interface with a high level of detail. By means of a meter scale, displayed on the right side of the road, the driver can see the distance to the vehicle ahead.

Figure 32 Current graphical user interface of the DISTRONIC Plus

The idea behind the concept “change of perspective” is to indicate the availability of the semi-automated lane change assistant by a change in perspective of the ego-vehicle. The change of perspective is intended to provide feedback on which assisted and automated mode is currently in use and should therefore encourage the driver´s mode awareness. Once the conditions for the semi-automated lane change assistant are met, the perspective of the shown scene changes. It is chosen to animate the change of perspective in order to support the driver´s understanding of the relation between the two illustrated perspectives.

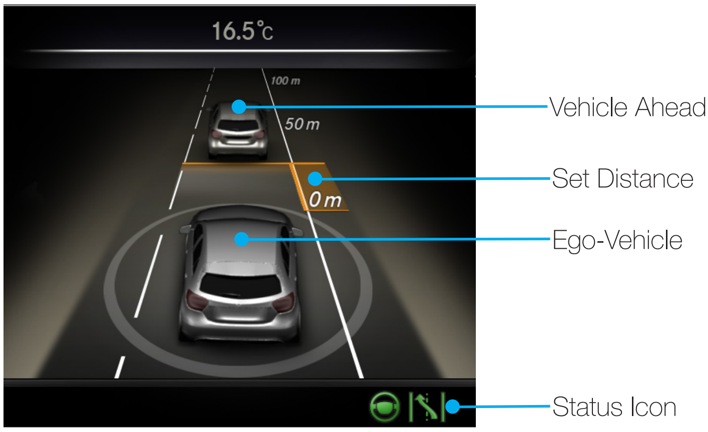


Figure 33 Change of perspective indicates the availability of the semi-automated lane change assistant

The new perspective shows the complete ego-vehicle in the rear view, from an elevation angle of about 40° (see figure 33). In this perspective, the ego-vehicle is surrounded by a ring, which is taken over from the previous concept of the semi-automated lane change assistant. The ring performs two functions. It symbolizes the 360° panoramic view of the sensors and is used to distinguish the ego-vehicle from the preceding vehicle. In addition to the change of the perspective, an icon in the status bar indicates the availability of the semi-automated lane change assistant. The color of the icon changes from gray to green as soon as the semi-automated lane change assistant is available. In order to keep the graphical user interface clear and concise, the only lane displayed is the ego-lane. The lanes next to the ego-lane are only partially displayed. The illustrated lane markings in the graphical user interface are a replica of the real driving environment and indicate to which side a semi-automated lane change is possible.

Figure 34 Visualization of the search phase

When the driver requests the semi-automated lane change, the color of the ring around the ego-vehicle gives feedback about the status of the system (see figure 34). A yellow, pulsating semicircle indicates that the system searches for a suitable gap on the target lane due to the fact that an immediate lane change is not possible. The depiction of the complete ego-vehicle from the chosen perspective in conjunction with the colored area of the ring around the ego-vehicle has the objective to direct the driver's situational awareness towards the areas that need to be monitored during the semi-automated lane change maneuver.

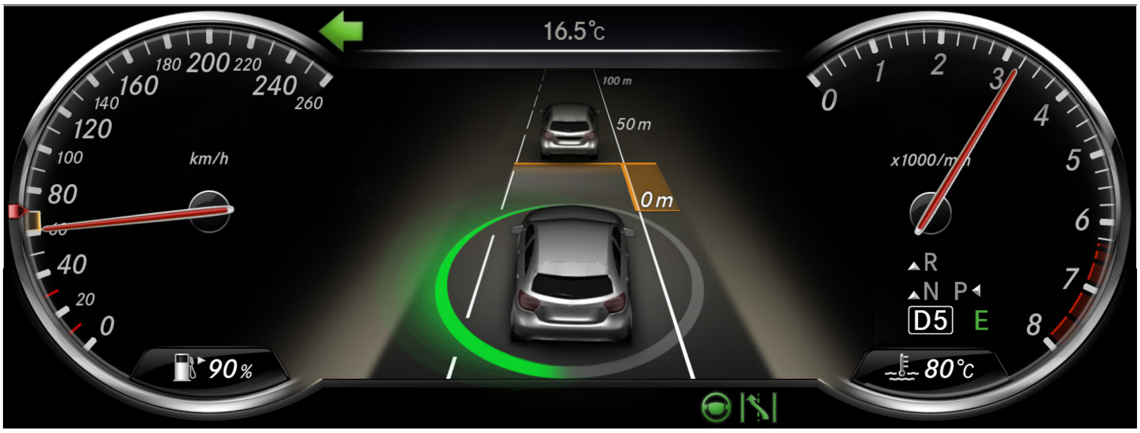


Figure 35 Visualization of the execution phase

Once the system has found a gap on the target lane or if the lane change is immediately possible after the request of the driver has been received, a green semicircle lights up (see figure 35). In contrast to the yellow semicircle, the green semicircle does not pulsate. The intention of this deviation from the existing concept is to differentiate the search phase from the execution phase by more than just the displayed color. The execution phase of the semi-automated lane change assistant is shown in the graphical user interface as an animation. During this animation, the lane markings move sideward in order to indicate that the ego-vehicle switches to the target lane.

Figure 36 Illustration of lane change recommendations

In addition to the system feedback of the semi-automated lane change assistant and the elements of the DISTRONIC Plus and the steering assistant, lane change recommendations are integrated into the graphical user interface as well. By means of a lane sensitive navigation, which combines camera data, GPS coordinates and map data, the exact position of the vehicle can be determined. [32] If the driver is not on the right lane according to the route guidance, the target lane and the lanes in between the ego-lane and the target lane are shown in the graphical user interface (see figure 36). Therefore, the driver knows exactly how many lane changes need to be executed in order to follow the route guidance. The target lane is emphasized by an arrow that displays the opportunity to switch lanes. Furthermore, the arrow indicates the time that the driver has to change to the target lane. The inclusion of the time aspect is intended to stimulate the driver to request the semi-automated lane change assistant on time so that the system has sufficient time to execute the lane change.

6.3.2 Concept "Multi-Lane"

The concept "Multi-Lane" shows the ego-vehicle in a camera perspective with an elevation angle of about 40°, as shown in figure 37. In contrast to the first concept, the complete ego-vehicle is permanently displayed in the rear view perspective. The meter scale on the right side of the road indicates the distance to the vehicle ahead. Due to the fact that similar elements can cause confusion in a graphical user interface, the vehicle ahead is displayed as a wireframe model. Therefore, the ego-vehicle and the vehicle ahead can clearly be distinguished by the driver.

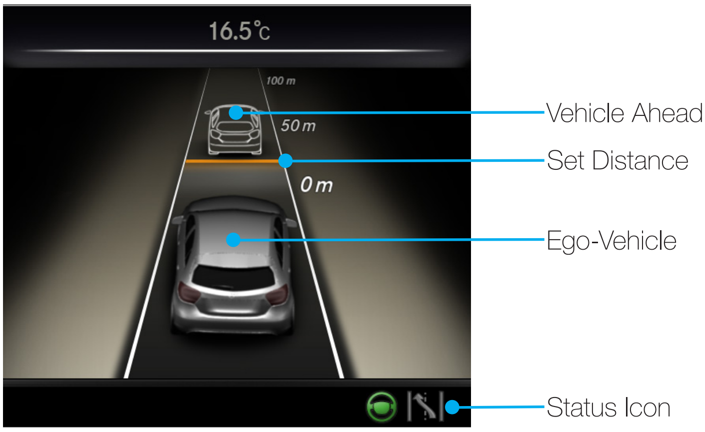


Figure 37 Semi-automated lane change assistant unavailable

When the conditions for the semi-automated lane change assistant are met, the available lanes next to the ego-lane fade in as visual feedback for the availability of the semi-automated lane change assistant (see figure 38). Based on the shown lanes, the driver can see in which mode the semi-automated lane change assistant is. Since the display area in the instrument cluster is limited and the semi-automated lane change maneuver cannot be executed over multiple lanes, only one lane to the left and one lane to the right of the ego-lane are illustrated. In addition to the display of the available lanes, the driver is informed by an icon, located in the status bar, about the availability of the semi-automated lane change assistant.

When the driver requests the semi-automated lane change, a yellow or green area next to the ego-vehicle appears, which gives feedback about the status of the system. The area

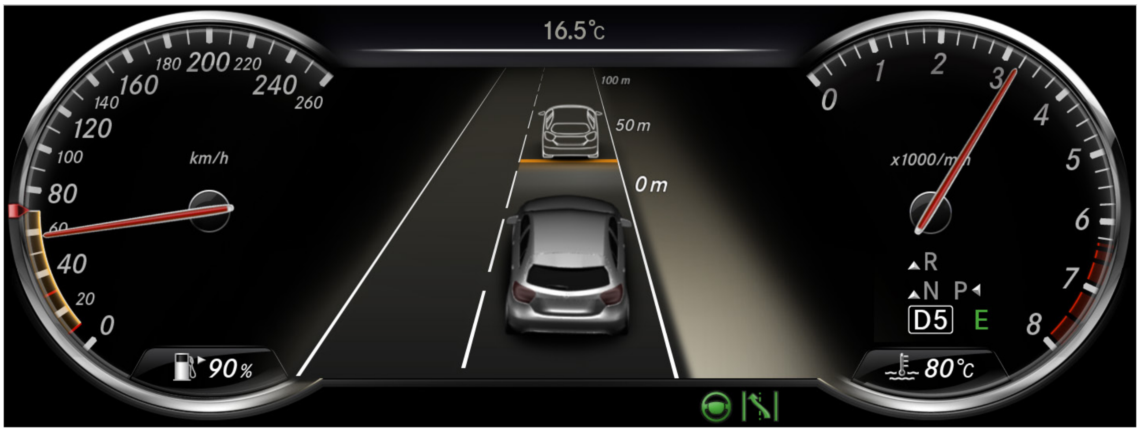


Figure 38 Illustration of available lanes next to the ego-lane as feedback for the availability of the semi-automated lane change assistant

metaphorically represents the field that is monitored by the sensors of the system. This visual representation is intended to illustrate the functionality of the system in a visual manner to the driver. Depending on whether the driver requests the semi-automated lane change to the left or to the right side, the area appears on the relevant side of the ego-vehicle. The large colored area as feedback for the system status is intended to be perceived in the driver´s peripheral field of view. This would have the advantage that the driver is not forced to focus on the instrument cluster in order to see the current status of the system.

Figure 39 Visualization of the search phase

If an immediate lane change is not possible, a yellow, pulsating area next to the ego vehicle indicates that the system searches for a suitable gap on the target lane. Vehicles that are located on the target lane during the search phase are illustrated as abstract shadows that move through the yellow pulsating area (see figure 39). This abstract representation of passing vehicles has been chosen in order to reduce the complexity of the graphical user interface. The objective of the illustration of the detected vehicles on the target lane is to encourage the driver to actively monitor the driving environment by matching the view of the system with the real driving environment. In this way, the driver´s situational awareness should be maintained as well as be directed to the areas that need to be monitored during the semi-automated lane change maneuver. When the system has found a gap on the target lane to execute the lane change, the color of the displayed area next to the ego-vehicle changes from yellow to green, as shown in figure 40. In order to clearly distinguish the search phase from the execution phase by more than the displayed color, the area next to the ego-vehicle pulsates during the search phase and stands still during the execution phase. The execution phase of the semi-automated lane change is represented in the graphical user interface as an animation comparable to the concept “change of perspective”. During this animation, the lane markings move sideward to illustrate the lane change of the ego-vehicle.

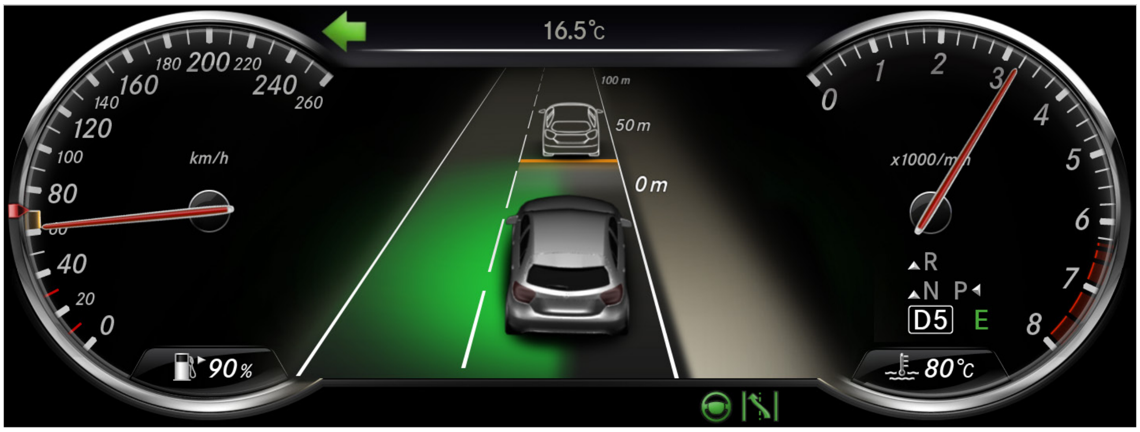


Figure 40 Visualization of the execution phase

In this concept, lane change recommendations are displayed in the same manner as in the concept “change of perspective”. If the driver is not on the right lane according to the route guidance, the target lane is shown in the graphical user interface (see figure 41). An arrow emphasizes which lane the driver has to take in order to follow the route guidance. Furthermore, the arrow gives feedback about the available time to change to the target lane.

Figure 41 Illustration of lane change recommendations

6.3.3 Concept “Top-View”

The concepts “Change of Perspective” and “Multi-Lane” are quite similar in their visual representation. Both concepts embody a high degree of detail and realism. In section 2.7 it has been shown that the graphical user interface for the same function can differ greatly in terms of the level of abstraction and detail. Therefore, an objective of the concept “Top-View” is to design an integrated graphical user interface that is more abstract and less detailed than the other two concepts. In the subsequent concept evaluation it can then be examined in how far an abstract and minimalistic representation is suitable for the representation of an integrated graphical user interface.

This concept shows the ego-vehicle from the top-view, as shown in figure 42. The perspective view that has been selected for the first two concepts is particularly suitable to illustrate what occurs in front of the vehicle. The depiction of the ego-vehicle in the top-view has the advantage that the entire vehicle environment can be represented. During a semi-automated lane change, the driver must also monitor the area behind the vehicle in order to detect approaching vehicles on the target lane. The representation of the ego-vehicle in the top-view has the advantage that the driver can better be informed about occurrences behind the vehicle. In this concept, the ego-vehicle is surrounded by colored ellipses with different diameters.

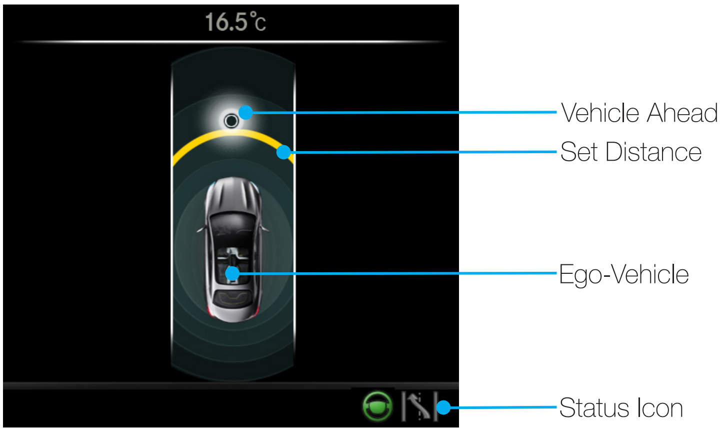


Figure 42 Semi-automated lane change assistant unavailable

These metaphorically represent the area that is monitored by the sensors of the vehicle and indicate the area in which the sensors are active. The ellipses are intended to symbolize a protective zone around the vehicle where the driver is supported by advanced driver assistance systems. The representation of the ego-vehicle in the top-view in connection with the ellipses around it, is based on the traffic collision avoidance display, which is used in modern aircraft (see figure 43). The aim of this graphical user interface is to inform the pilot about other aircraft in the surrounding area in order to avoid possible collisions.

Figure 43 Traffic collision avoidance display

The display shows the own aircraft in a central position in the top-view. Planes that are located around the own aircraft are illustrated as abstract points, rectangles or rhombuses. This abstract representation is also used for the depiction of the detected vehicles around the ego-vehicle in the “top-view” concept. When a vehicle is detected by the sensors of the system, it is shown as a white point that approaches the ego-vehicle or moves away from it, as depicted in figure 44. The meter scale is omitted in this concept in order to prevent a cluttered graphical user interface.The colored sensor area and the lane markings beside the ego-vehicle are intended to

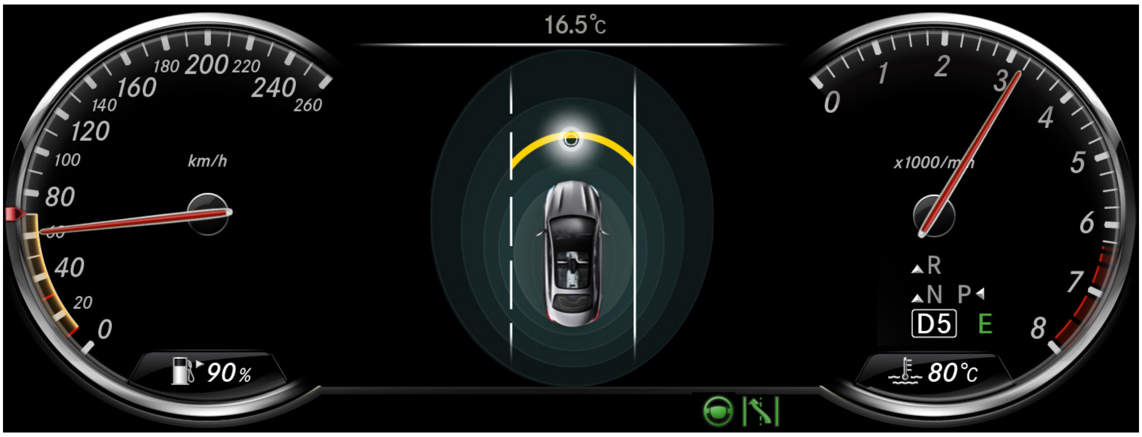


Figure 44 Change of colored sensor area and lane markings as feedback for the availability of the semi-automated lane change assistant

visualize the mode of the semi-automated lane change assistant. When the semi-automated lane change assistant is passive, the lane markings are solid and the colored sensor area around the car is reduced to the longitudinal direction. Once the semi-automated lane change assistant is available, the lane markings change their visual appearance from solid to dashed. Additionally, the sensor area around the ego-vehicle expands in the transversal direction over the lane markings in order to illustrate the assistance through the semi-automated lane change assistant (see figure 44). Furthermore, the driver is informed by an icon in the status bar about the availability of the semi-automated lane change assistant.

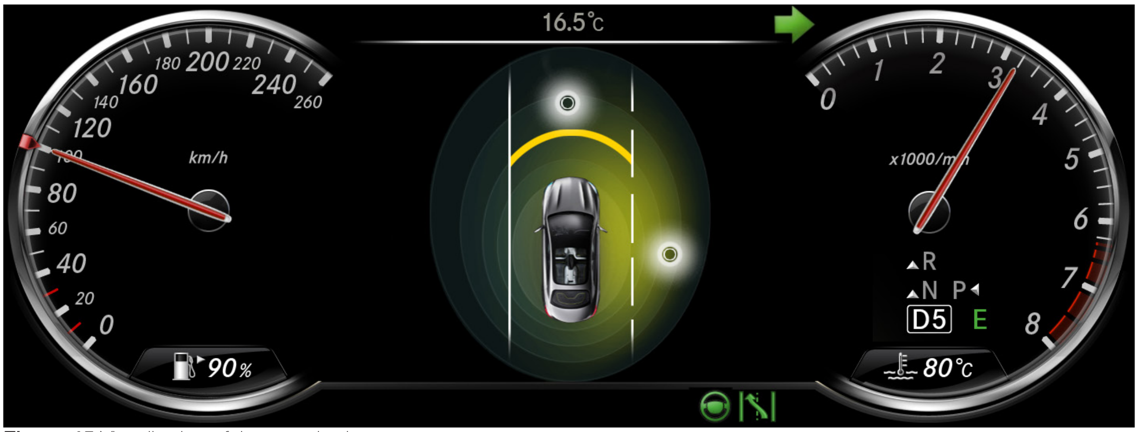


Figure 45 Visualization of the search phase

If the driver requests the semi-automated lane change, a yellow or green area next to the ego-vehicle appears, as shown in figure 45. This area indicates the system status of the semi-automated lane change maneuver. Depending on the side of the requested lane change, the area appears on the left or right side of the ego-vehicle. Corresponding to the concept “Multi Lane”, a yellow, pulsating area clarifies that the system searches for a suitable gap on the target lane. During the search phase, passing vehicles on the target lane are displayed as abstract points that move along the ego-vehicle. The aim of this illustration is to stimulate the driver to compare the view of the system with the real driving situation to maintain awareness of the traffic environment around the car. Therefore, the driver´s situational awareness should be maintained and be directed to the areas that need specific attention during the semi-automated lane change maneuver.

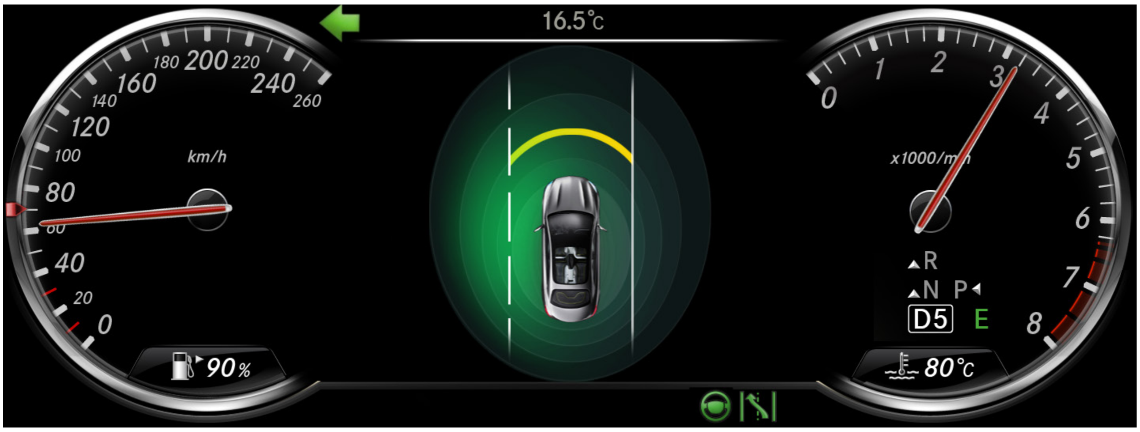


Figure 46 Visualization of the execution phase

A green area next to the ego-vehicle displays the execution of the semi-automated lane change maneuver (see figure 46). For a clear difference between the search phase and the execution phase the area next to the ego-vehicle pulsates during the search phase and stands still during the execution phase. In comparison to the other two concepts, the execution of the semi-automated lane change is not shown as an animation where the lane markings move across the street. Instead, the lane markings are adapted to the corresponding situation by means of a cross-fade effect. This reduced graphical representation of the lane change process is chosen in order to prevent that the attention of the driver is bound to the instrument cluster during the semi-automated lane change maneuver.

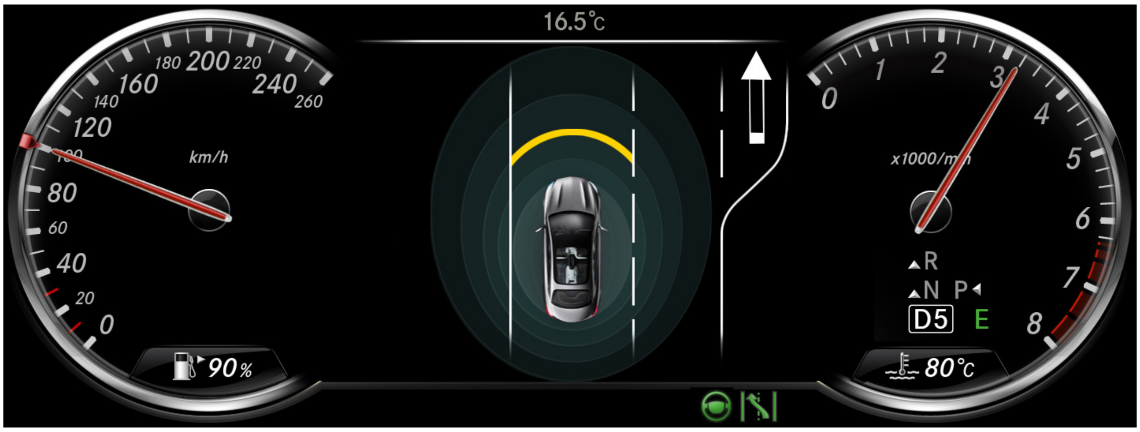


Figure 47 Illustration of lane change recommendations

Lane change recommendations are integrated into this concept in a similar way as in the previous two concepts. If the system detects that the vehicle is not on the lane conform to the route guidance, the target lane fades in (see figure 47). The target lane in the graphical user interface is indicated by an arrow that provides feedback about the time the driver has to change to the target lane.

CHAPTER 7
Evaluation and Further Improvements

This chapter covers the evaluation of the three concepts described in the previous section. A usability evaluation is carried out to choose the concept with the most potential. In the last part of this chapter the chosen concept is further developed based on the feedback of the evaluation. The concepts presented in chapter 6 consider only optimal conditions for the semi-automated lane change. However, as described in chapter 5, there are scenarios where the semi-automated lane change assistant system reaches its limit and driver intervention becomes necessary. An in depth analysis of the graphical user interface in such circumstances is beyond the scope of this study. However, a brief description on what the graphical user interface could display in critical semi-automated lane change scenarios is provided.

7.1 Usability-Evaluation

The evaluation of the graphical user interface concepts is carried out to identify possible weak points for the further optimization of the design. Depending on the development phase of the graphical user interface, there are different evaluation methods. [24] Basically, summative and formative evaluation methods can be distinguished. Summative evaluation methods are used at the end of the development phase in order to evaluate the finished user interface. In contrast, formative methods are used during the development of a graphical user interface in order to optimize the design. Moreover, it can be differentiated between user-orientated and expert-orientated evaluation methods. User-orientated evaluation methods involve future users in the evaluation of the graphical user interface. Expert-orientated methods involve user interface experts, who evaluate graphical user interfaces based on selected usability criteria. The concepts for the integrated graphical user interface of the semi-automated lane change assistant system are currently in an early development phase. Therefore, a formative, expert-orientated evaluation is chosen as evaluation method.

7.1.1 Evaluation Criteria

This section describes the selected criteria for the expert-orientated evaluation of the integrated graphical user interface. In the European project RESPONSE 3, a “Code of Practice” for the design and evaluation of advanced driver assistance systems has been developed by a group of automotive manufacturers, suppliers, government agencies and research institutes. [10] The “Code of Practice” includes, amongst others, a list of questions for the evaluation of driver assistance systems (Checklist B, A26-A40). This questionnaire contains a total of 102 questions from different areas suitable for the evaluation of driver assistance systems. Since the questionnaire is not limited to graphical user interface specific questions, not all questions are relevant for the evaluation. Therefore, ten questions have been selected which are particularly suitable for the evaluation of the graphical user interface of the semi-automated lane change assistance system. In particular, the questionnaire for the expert evaluation contains the following questions from the different categories:

Category	Question
Predictability	Does the driver get a clear understanding of the different modes of operation / system states?
Trust	Are system messages, which are relevant for the driving task, appropriate (in type, frequency) with respect to the situation?
Perceptibility (message transfer to driver)	Is the driver sufficiently informed about the system status and function at all times?

Perceptibility (message transfer to driver)	Are the system messages comprehensible and unambiguous for the driver?
Vigilance	Does the HM Interaction of the system prevent the driver from losing situational awareness (e.g. keeping the driver“ in the loop”, providing a consistent warning strategy)?
Workload / Fatigue	Is the HMI layout constructed in a way such as to avoid an overload of the driver’s sensory channels in ADAS specific traffic situations?
Traffic safety / Risk	Is the system function self – explanatory (i.e. without user manual)?
	Can the operation or observation of the system (e.g. possible driver distraction by displays) be achieved without a major change in attention distribution relating to the driving task so that potentially hazardous situations may not occur?
Learnability	Is it likely that the driver’s mental representation of the system, which they will develop during operation, will correspond to the technical function (compatibility of mental and technical model)?
Behavioral changes	Does the driver understand the system feedback to their performed input / control actions (feedback could be e.g. acoustical, optical or dynamic vehicle behavior)?

Table 9 Selected questions for the expert-orientated evaluation of the developed concepts

7.1.2 Evaluation Process

The evaluation of the concepts was performed at the Daimler AG, with eight user interface experts. The process of the evaluation was divided into four steps. In the first step, the overall functioning of the semi-automated lane change assistant was explained. During the second step, the three concept animations were demonstrated and explained. In the third step of the evaluation, the user interface experts filled in the questionnaire with the selected usability criteria. In the last part, a discussion was initiated so that the experts could agree on the basis of the evaluation criteria and their personal opinion on the best of the three concepts presented.

7.2 Evaluation Results

In this section the results of the formative, expert-orientated evaluation are presented. Based on the completed questionnaires and the open discussion, the strengths and weaknesses of each concept are identified and discussed. An overview of the comments of the user interface experts on the selected usability criteria can be found in appendix D.

7.2.1 Concept “Change of Perspective”

According to the user interface experts, the change of perspective in combination with the status icon support a clear understanding of the different modes of the semi-automated lane change assistant. From the experts’ point of view, the illustration of no further lanes beside the ego-lane makes the graphical user interface appear clearly and uncluttered. In this context, it was also mentioned that the representation of no passing vehicles in the graphical user interface could animate the driver to actively observe the driving environment in order to monitor the activity of the system. Furthermore, it was stated that the ring around the ego-vehicle is well integrated into the whole graphical user interface. According to the experts, it informs the driver with its simplicity clearly about the current status of the system. The change of perspective by itself was negatively evaluated by almost all experts. The change of perspective clearly indicates the mode of the system, however, a frequent change of the perspective could lead to an increased disturbance of the graphical user interface. From the experts’ point of view, the change of perspective could result in an additional visual workload of the driver and could distract the driver from the driving activity. In addition, two experts criticized the displayed lane markings as too thin and therefore difficult to perceive for the driver. Five out of eight experts have selected this concept as the favorite concept. However, four of the five experts mentioned explicitly that they would prefer the permanent illustration of the ego-vehicle in the rear view perspective without the change of perspective. The permanent illustration of the ego-vehicle in the new perspective would imply that the existing illustration of the DISTRONIC Plus needs to be adapted to the new perspective.

7.2.2 Concept “Multi Lane”

The permanent display of the ego-vehicle in the rear view perspective was positively evaluated by the experts. This representation leads to a more balanced graphical user interface that burdens and deflects the driver less compared to the change between different perspectives. According to the experts, the fade-in of the available lanes in combination with the status icon creates a clear feedback of the mode of the system and is clearly visible for the driver. Furthermore, the wireframe representation of the vehicle ahead was positively evaluated due to the fact that it prevents the confusion between the ego-vehicle and the preceding vehicle. According to the experts, the status of the system is shown clearly by the large colored areas next to the ego-vehicle and can easily be seen by the driver. The illustration of the passing vehicles during the search phase was both positively and negatively evaluated. On the one hand, the display of the detected vehicles could strengthen the driver´s confidence in the system because it supports comprehension which vehicles are recognized by the system. However, overconfidence could lead to the situation that the driver solely relies on the presented information of the graphical user interface. This would result in reduced situational awareness of the driver due to fewer looks in the rear view mirrors in order to actively monitor the driving environment. Almost all experts rated the chosen representation of the passing vehicles as too abstract. Due to the large degree of abstraction it could be difficult for the driver to understand the relationship between the illustration of the passing vehicles in the graphical user interface and the vehicles in the real driving environment. It was also noted that the chosen representation of the passing vehicles could be misinterpreted as possible gaps on the target lane. Additionally, the pulsating area next to the ego vehicle in combination with the abstract illustration of the passing vehicles during the search phase was criticized as an additional visual workload on the driver. All in all, two out of eight experts favored this concept as best concept.

7.2.3 Concept Top-View

The idea of the visual representation of the available driver assistance in longitudinal and transverse direction was positive mentioned by the experts. Due to this representation, the driver can clearly understand when the semi-automated lane change assistant is available or unavailable. Furthermore, the experts mentioned that the top-view perspective in combination with the illustration of the passing vehicles enables the driver to see at a glance where other vehicles are located. According to the experts, the driver is therefore the least surprised about the current driving situation at a sudden transition to a lower mode of automation. From the experts' point of view, the visual illustration of the search and execution phase of the semi-automated lane change assistant is clearly and easily to perceive while driving. The depiction of the vehicles on the lanes next to the ego-lane, however, was also seen negatively. It could lead to a reduction of looks into the rear and side view mirror in order to monitor the real driving environment. Therefore, the display of passing vehicles would result in a reduced situational awareness of the driver. In general, the concept has been evaluated as too abstract. Compared to the other two concepts, the neglected meter scale displaying the distance to the vehicle ahead was criticized. From the experts' point of view, the chosen graphical representation makes it difficult for the driver to estimate the distance to the vehicle ahead. The abstract illustration of the vehicles around the ego-vehicle is a further identified weak point of this concept. According to the experts, the abstract illustration of the vehicles is ambiguous and could be interpreted by the driver as static obstacles. Furthermore, it was mentioned that the representation of the ego-vehicle from the top-view has the disadvantage that the driver must decode the shown scene. This means that the driver has to transfer the displayed information from the top-view perspective to the real driving environment. From the experts' point of view, this transformation could lead to an increased workload for the driver. The concept "Top-View" was favored by one of the eight experts as the best concept.

7.3 Second Iteration

Based on the evaluation and the preference of the user interface experts, the concept "Change of Perspective" was chosen to be further developed. The second iteration of the chosen concept incorporates two aspects. On the one hand, it includes the feedback from the expert-orientated evaluation and on the other hand, it considers how the graphical user interface could inform the driver about the status of the system in critical lane change situations. For a clear representation of the second iteration an animation is developed, which can be found on the accompanying DVD.

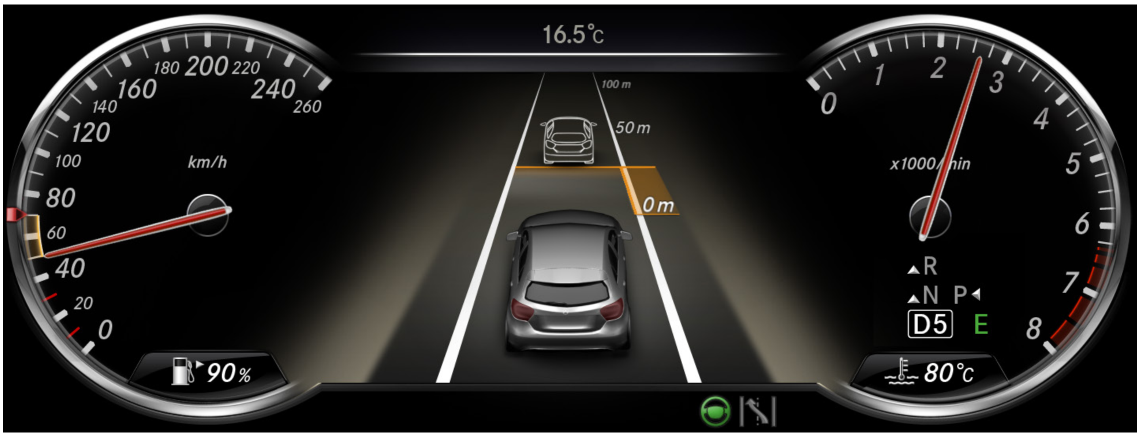


Figure 48 Semi-automated lane change assistant unavailable

According to the feedback from the evaluation, the second iteration forgoes the change of perspective. Instead, the ego-vehicle is permanently shown in the rear view perspective, as shown in figure 48. Based on the feedback of the evaluation, the lane markings are broadened in order to be clearly visible for the driver. Due to the fact that the ring around the ego-vehicle has no function when the semi-automated lane change assistant is passive, it fades in as soon as the semi-automated lane change assistant gets active. The display of the ring serves thus, next to the lane markings and the status icon, as additional feedback for the availability of the semi-automated lane change assistant (see figure 49). In order to clearly differentiate the ego-vehicle and the vehicle ahead, the preceding vehicle is illustrated as a wireframe model.

Figure 49 Lane markings and ring around ego-vehicle serve as feedback for the availability of the semi-automated lane change assistant

Figure 50 Visualization of the search phase

Figure 51 Visualization of the execution phase

In section 5.1 different lane change scenarios that could lead to a breakup of the semi-automated lane change maneuver have been analyzed. Next to the improvements based on the evaluation, it is considered how the graphical user interface could inform the driver about a possible breakup of the semi-automated lane change maneuver. If the lane change maneuver needs to be canceled during the search phase due to high traffic volume on the target lane, it should be clearly indicated by the graphical user interface. Especially in situations where a lane change becomes obligatory, forced by the layout of the road for example, the driver should be informed clearly and concisely in order to have enough time to execute the necessary lane change manually. Therefore, it is chosen to inform the driver about the abortion of the search phase by means of a text message pop-up, as depicted in figure 52.

Figure 52 Information about the termination of the search phase by means of a text message pop-up

As soon as the search phase is canceled, the assistance graphic fades out and the pop-up appears in the center of the instrument cluster. The objective of the pop-up message is to attract the driver´s attention in order to clearly communicate the abortion of the semi-automated lane change maneuver. A text message pop-up is preferable because the driver can additionally be informed about the reason why the search phase is broken up. The feedback about breakup should make the system behavior more transparent and comprehensible for the driver. Furthermore, the message enables the driver to build a sufficient mental model of system in order to evaluate the behavior of the system properly at any time. [22]

Besides an interruption of the search phase, it is also possible that the maneuver needs to be canceled while the lane change is executed. A possible scenario might be that a fast vehicle approaches on the target lane that has not been identified by sensors during the search phase of the semi-automated lane change maneuver. Since the driver has the task to monitor the driving environment before and during the semi-automated lane change, the approaching vehicle should be noticed. However, if the approaching vehicle is not detected by the driver, the active blind spot assistance system warns the driver visually, acoustically and even takes active control to evade the approaching vehicle. As soon as the active blind spot assistant detects a dangerous situation due to an approaching vehicle, the execution of the semi-automated lane change should be canceled. Thus, the warning of the active blind spot assistant and the abortion of the semi-automated lane change maneuver are related to each other. Due to this relation, it is chosen to integrate the visual warning of the active blind spot assistant into the assistance graphic of the semi-automated lane change assistance system. When an approaching vehicle is detected during the execution of the semi-automated lane change, the ring around the ego-vehicle changes its color from green to red (see figure 53,54).

Figure 53 Breakup of the execution phase due to a fast approaching vehicle from behind

Figure 54 Breakup of the execution phase due to an approaching vehicle from the far-adjacent lane

The red colored ring indicates that the semi-automated lane change maneuver is canceled due to a detected vehicle on the target lane by the active blind spot assistant. The chosen graphical representation of the ego-vehicle with the surrounding ring offers the possibility to produce a position related warning. Based on the position of the detected vehicle by the active blind spot assist, the corresponding area of the ring is colored. Therefore, the driver gets the additional feedback that the semi-automated lane change maneuver is canceled due to an approaching vehicle from behind or from the side. The integration of the visual warning of the active blind spot assistant is a further step towards an integrated driver assistance graphic that combines the information from different advanced driver assistance systems in one clearly arranged graphical user interface.

CHAPTER 8

Conclusion and Recommendation

The rising number of advanced driver assistance systems with different levels of automation poses a challenge for car manufacturers in order to design interfaces that can be understood by the driver in a simple and intuitive way.

In the context of this thesis, three integrated graphical user interface concepts for the semi-automated lane change assistance system have been created. The development of the concepts is based on established requirements that result from the analysis of various lane change scenarios and ergonomic guidelines for the design of graphical displays. In order to better experience the developed concepts under real driving conditions, they have been animated and tuned to a filmed usage scenario. The outcome of this thesis is a graphical user interface that combines the display contents of the semi-automated lane change assistant with the advanced driver assistance systems “DISTRONIC Plus with steering assistant” and Active Blind Spot Assist.

One of the most important questions during the development of the integrated graphical user interface, was to determine the right degree of detail and abstraction for the displayed driver assistance relevant information. In order to find an answer to this question, concepts with different levels of detail and abstraction have been developed. Based on the conducted expert-orientated evaluation, it is expected that a reduced graphical user interface supports the driver´s situational awareness. However, too abstract and reduced representations of the system information can easily lead to misunderstanding and an increased workload of the driver. However, it should be taken in mind that the created concepts were not evaluated in a dynamic driving context and therefore without the inclusion of the driving environment and the driving task. It is quite conceivable that an abstract and reduced representation of the relevant driver assistance information is more comprehensible when the driver is actively involved in the driving environment.

The validation of the developed concepts in a dynamic driving context should therefore be the next step in the evaluation process. In order to evaluate the concepts under real driving conditions, a field study or driving simulator study would be preferable. Therefore, the effect of the concepts on the driver could be determined under realistic conditions in order to further optimize the concepts. Moreover, it should be examined, which additional advanced driver assistance information could be integrated in the graphical user interface in order to increase the efficiency of the interface. Considering the future development of highly and fully automated driving, it would also be interesting to investigate how the graphical user interface concept, resulting from this thesis, could be augmented to support advanced driver assistance systems with higher levels of automation.

Index / Tables and Figures

Appendix

Appendix A: European Statement of Principles on the Design of Human Machine Interaction (ESoP)[1]

The following list presents selected principles from different categories of the ESoP catalog that are suitable for the design of graphical user interfaces.

Category Design Goal:

1. The system supports the driver and does not give rise to potentially hazardous behaviour by the driver or other road users.

2 The allocation of driver attention to the system displays or controls remains compatible with the attentional demands of the driving situation.

3. The system does not distract or visually entertain the driver.

4. The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users.

5. Interfaces and interaction with systems intended to be used in combination by the driver while the vehicle is in motion are consistent and compatible.

Category Information Presentation Principles:

1. Visually displayed information presented at any one time by the system should be designed such that the driver is able to assimilate the relevant information with a few glances which are brief enough not to adversely affect driving.

2. Internationally and/or nationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used.

3. Information relevant to the driving task should be accurate and provided in a timely manner.

4. Information which has the highest safety relevance should be given priority.

5. System generated sounds, with sound levels that can not be controlled by the driver, should not mask audible warnings from within the vehicle or the outside.

1Source: http://www.imobilitysupport.eu/library/imobility-forum/working-groups/active/human-machine-interaction/other-reports-5/2416-hmi-wg-esop-hmi-01-jun-2005-1/file, accessed 15.11.2014

Category Interaction with Displays and Controls:

1. The systems response (e.g. feedback, confirmation) following driver input should be timely and clearly perceptible.

2. Systems providing non-safety related dynamic visual information should be capable of being switched into a mode where that information is not provided to the driver.

Category System Behaviour Principles:

1. While the vehicle is in motion, visual information not related to driving that is likely to distract the driver significantly should be automatically disabled, or presented in such a way that the driver cannot see it.

2. The behaviour of the system should not adversely interfere with displays or controls required for the primary driving task and for road safety.

3. Information should be presented to the driver about current status, and any malfunction within the system that is likely to have an impact on safety.

Category Information about the system:

1. System instructions should be correct and simple.

2. System instructions should be in languages or forms designed to be understood by the intended group of drivers.

3. The instructions should clearly state which aspects of the system are intended to be used by the driver while driving and those aspects (e.g. specific functions, menus etc.) which are not intended to be used by the driver while driving.

Appendix B: ISO Standard 9241-12[2]

ISO 9241-12 defines the following requirements for the presentation of visual information:

1. Clarity
"The information content is communicated quickly and accurately"

2 Source: http://www.cheval-lab.ch/was-ist-usability/usability-grundlagen/normen-und-richtlinien/iso-9241-12/, accessed 15.11.2014

2. Distinctness
"The displayed information can be accurately distinguished"

3. Compactness
"The users are provided with the information that is necessary for completing the task"

4. Consistency
"Same information is always presented in the same way within the application according to the user's expectations."

5. Recognizability
"The user's attention is directed to the required information."

6. Legibility
"The information is easy to read"

7. Intelligibility
"The meaning is easily understood, clearly interpretable and recognizable"

Appendix C: Thirteen Principles of Display Design

Wickens et al. (2003, p. 186) defined 13 principles of display design to develop effective displays that support the perception of relevant system variables and facilitate the processing of that information. The principles are categorized into perceptual, mental model, attention and memory principles.

Perceptual Principles

The perceptual principles are about the way a user perceives information that is presented on visual displays. They describe how to present information in a clear and understandable manner to avoid confusion by the user. In total there are five perceptual principles.

1.Make display legible
Displays must be legible in order to allow the user to interact with it in a successful way. Therefore, the contrast, the combination of colors, the salience and the masking of the display should be correct to ensure that the user perceives all necessary information from the display.

2.Avoid absolute judgment limits
To minimize the confusion during the interpretation of display information, it should be avoided to use only one sensory variable such as color or size. Those variables alone can contain many possible levels and therefore could be interpreted in a wrong way.

3. Top-down processing
The user perceives and interprets information based on past experiences. If a display presents

information that is not in line with the expectation of the user, it can happen that the user sees what he expects instead of what the display really shows. Therefore, information that is contrary to the expectation of the user must be presented in a clear and noticeable manner.

4. Redundancy gain

To support the right interpretation of information in degraded viewing conditions, information should be presented in more than one way. By using color and position, the user is still able to interpret the information correctly by means of the position if he cannot see which color it is. A good example of this is the traffic light.

5. Discriminability.

Similarity causes confusion. Use discriminable elements. Information that appears to be similar can lead to confusion by the user. The ratio of similar features to different features leads to the similarity of information. To avoid confusion caused by similar elements, the use of unnecessary similar elements should be prevented and dissimilar elements should be highlighted.

Mental Model Principles

Users interpret the information on displays according to their experience and expectations. Based on past experiences users have built up mental models of systems and their working principles. Therefore, displays should be designed to be consistent with the mental model of the user. There are two mental model principles that should be considered when designing visual displays.

6. Principle of pictorial realism

A display should be designed in a manner that it looks like the variable it represents to support the expectations of the user. When there are a lot of elements, they can be organized in a way that they look like the environment they represent.

7. Principle of moving part

Moving elements in dynamic displays should move in the same direction as expected by the user and represented by the physical world. An example is the ACC display that shows more lines to indicate more distance to the car ahead and fewer lines to show the decreasing distance.

Principles Based on Attention

A lot of displays contain different kinds of information. Therefore, the user must spread his attention to a number of different elements at the same time. The following three principles support the design of displays with an appropriate layout so that the user can access the important information easily.

8. Minimizing information access cost

Finding the correct information on a display takes time and effort. A good display design keeps the needed time and effort as low as possible. To achieve this goal, the most important and accessed information should be presented at a central location. If a color change is the most important source of information, then it should also be the most salient. Furthermore, a low access cost can be achieved by using a small display area so that user does not has to search for information in a too wide area.

9. Proximity compatibility principle

In some cases, the user must integrate more than one source of information to conduct a task. Therefore, those sources of information should have a close mental proximity. Next to nearness in space, a close mental proximity of information sources can be achieved for example by using common colors, patterns or shapes.

10. Principle of multiple resources

The human capability of receiving a lot of information at the same time is limited. Spreading the presentation of information across different resources can make it easier for the user to process different information at once. Instead of presenting all information visually it is more effective to use visual and auditory information concurrently.

Principles Based on Memory

The principles based on memory address the fact that the human working memory and long term memory have limitations. It is only possible to keep a small amount of information in the working memory and information in the long term memory can be forgotten. The following principles address those limitations and help to support the human capabilities.

11. Replace memory with visual information: knowledge in the world

Due to the limited memory capabilities of the human user, a display can support the user by replacing memory with visual information. A user should not has to retain important knowledge about the working principle of a system from the working memory or retrieve it from the long term memory. Good visual displays balance the knowledge in the user´s head and the knowledge in the world. Presenting information that directly resemble what is happening in the real world can help to decode the information more easily.

12. Principle of predictive aiding

The prediction of a situation is a task that has a high demand on the working memory. Predictive displays help the user with this complex task by showing something about possible future happenings, instead of reactively respond to user's actions. Therefore, the predictive display reduces the difficult cognitive task with a simpler perceptual one.

13. Principle of consistency

The principle of consistency is related to long-term memory information. Habits from the interaction with other displays lead to actions that are expected to be appropriate when interacting with new display. Therefore, good displays should be designed in way that they are consistent with different kinds of display designs.

Appendix D: Comments of User Interface Experts on Usability Criteria

Selected comments on the concept "Change of Perspective":

Question	Expert Comment
Does the driver get a clear understanding of the different modes of operation / system states?	The change of perspective in combination with the icon in the status bar give a clear feedback about the modus of the system
Are system messages, which are relevant for the driving task, appropriate (in type, frequency) with respect to the situation?	The change of perspective could be triggered too often caused by the layout of the road. This could lead to an additional visual workload on the driver
Is the driver sufficiently informed about the system status and function at all times?	The ring with its simplicity informs the driver clearly about the system status
Are the system messages comprehensible and unambiguous for the driver?	The illustration of the lane markings are very thin and therefore difficult to see for the driver
Does the HM Interaction of the system prevent the driver from losing situational awareness (e.g. keeping the driver" in the loop", providing a consistent warning strategy)?	The illustration of no vehicles next to the ego-vehicle and the vehicle ahead could lead to more looks into the mirror in order to scan the driving environment. Therefore, it is possible that the chosen illustration prevents the driver from losing situational awareness.
Is the HMI layout constructed in a way such as to avoid an overload of the driver's sensory channels in ADAS specific traffic situations?	A frequent change of perspective could lead to an overload of the drivers sensory channels The frequency of the change of perspective can not be planed because it depends on the layout of the road
Is the system function self – explanatory (i.e. without user manual)?	The graphical user interface communicates clearly and easy to understand the function of the system
Can the operation or observation of the system (e.g. possible driver distraction by displays) be achieved without a major change in attention distribution relating to the driving task so that potentially hazardous situations may not occur?	The animation of the change of perspective could distract the driver from the monitoring of the driving environment
Is it likely that the driver's mental representation of the system, which they will develop during operation, will correspond to the technical function (compatibility of mental and technical model)?	The graphical representation of the concept supports the formation of a correct mental model of the system function
Does the driver understand the system feedback to their performed input / control actions (feedback could be e.g. acoustical, optical or dynamic vehicle behavior)?	The feedback given by the graphical user interface stands in clear relation to the input of the driver in order to trigger the function.

Selected comments on the concept “Multi-Lane”:

Question	Expert Comment
Does the driver get a clear understanding of the different modes of operation / system states?	The fade-in of the available lanes in combination with the status icon creates a clear feedback of the mode of the system and is clearly visible for the driver
Are system messages, which are relevant for the driving task, appropriate (in type, frequency) with respect to the situation?	The pulsating area next the ego vehicle (search phase) in combination with the abstract illustration of the passing vehicles could result in an additional visual workload on the driver
Is the driver sufficiently informed about the system status and function at all times?	The status of the system is shown clearly by the large colored areas next to the ego-vehicle (search and execution phase) and can easily be seen by the driver
Are the system messages comprehensible and unambiguous for the driver?	The chosen representation of the passing vehicles is very abstract. Due to the large degree of abstraction it could be difficult for the driver to understand the relationship between the illustration of the passing vehicles in the graphical user interface and the vehicles in the real driving environment
Does the HM Interaction of the system prevent the driver from losing situational awareness (e.g. keeping the driver“ in the loop”, providing a consistent warning strategy)?	The illustration of the passing vehicles could lead to the situation that the driver solely relies on the presented information of the graphical user interface. This could result in reduced situational awareness of the driver due to fewer looks in the rear view mirrors in order to actively monitor the driving environment
Is the HMI layout constructed in a way such as to avoid an overload of the driver’s sensory channels in ADAS specific traffic situations?	The animation of the passing vehicles during the search phase could lead to an overload of the driver´s visual sensory channel
Is the system function self – explanatory (i.e. without user manual)?	The graphical user interface communicates in a comprehensible manner the function of the system.
Can the operation or observation of the system (e.g. possible driver distraction by displays) be achieved without a major change in attention distribution relating to the driving task so that potentially hazardous situations may not occur?	The abstract depiction of the moving vehicles on the side lane during the search phase could bind the driver situational awareness to the instrument cluster
Is it likely that the driver’s mental representation of the system, which they will develop during operation, will correspond to the technical function (compatibility of mental and technical model)?	The graphical representation clearly communicates the function of the system and supports the formation of a correct mental model of the functioning
Does the driver understand the system feedback to their performed input / control actions (feedback could be e.g. acoustical, optical or dynamic vehicle behavior)?	The graphical user interface creates a clear and comprehensible feedback according to the input of the driver

Selected comments on the concept “Top-View”:

Question	Expert Comment
Does the driver get a clear understanding of the different modes of operation / system states?	The idea of the visual representation of the available driver assistance in longitudinal and transverse direction creates a comprehensible feedback in order to illustrate when the semi-automated lane change assistant is available or unavailable.
Are system messages, which are relevant for the driving task, appropriate (in type, frequency) with respect to the situation?	The top-view perspective in combination with the illustration of the passing vehicles enables the driver to see at a glance where other vehicles are located. Therefore, driver is the least surprised about the current driving situation at a sudden transition to a lower mode of automation
Is the driver sufficiently informed about the system status and function at all times?	The visual illustration of the search and execution phase of the semi-automated lane change assistant is clearly and easy to perceive while driving
Are the system messages comprehensible and unambiguous for the driver?	The abstract illustration of the vehicles is ambiguous and could be interpreted by the driver as static obstacles The neglected meter scale displaying the distance to the vehicle ahead makes it difficult for the driver to estimate the distance to the vehicle ahead
Does the HM Interaction of the system prevent the driver from losing situational awareness (e.g. keeping the driver“ in the loop”, providing a consistent warning strategy)?	The depiction of the vehicles on the lanes next to the ego-lane could lead to a reduction of looks into the rear and side view mirror in order to monitor the real driving environment
Is the HMI layout constructed in a way such as to avoid an overload of the driver’s sensory channels in ADAS specific traffic situations?	The representation of the ego-vehicle from the top-view has the disadvantage that the driver must decode the shown scene. This means that the driver has to transfer the displayed information from the top-view perspective to the real driving environment
Is the system function self – explanatory (i.e. without user manual)?	Due to the abstract illustration of this concept it may be more difficult for the driver to understand the function and the feedback of the system
Can the operation or observation of the system (e.g. possible driver distraction by displays) be achieved without a major change in attention distribution relating to the driving task so that potentially hazardous situations may not occur?	The abstract depiction of this concept could bind the drivers attention to the instrument cluster in order to decode the presented scene
Is it likely that the driver’s mental representation of the system, which they will develop during operation, will correspond to the technical function (compatibility of mental and technical model)?	Due to the abstract illustration it may be more difficult to built up a correct mental model of the technical function
Does the driver understand the system feedback to their performed input / control actions (feedback could be e.g. acoustical, optical or dynamic vehicle behavior)?	The given feedback by the graphical user interface according to the performed input is clear and comprehensible

References

[1] Daimler AG (2014) *Daimler Company* [Online]. Availible: http://www.daimler.com/company, accessed: 04.06.2014

[2] Daimler AG (2014) *Wir gestalten die Zukunft: Mobilität ist der Motor für Wachstum und Wohlstand jeder modernen Gesellschaft* [Online]. Availible: http://www.daimler.com/dccom/0-5-7165-49-1391946-1-0-0-0-0-0-0-0-0-0-0-0-0-0-0.html, accessed: 25.11.2014

[3] Knoll, Peter (2010): Fahrerassistenzsysteme. *In*: Reif, Konrad (eds.): *Fahrstabilisierungssysteme und Fahrerassistenzsysteme: p.104-116;* Wiesbaden (Vieweg+Teubner Verlag)

[4] Bertels, Arne (2012): Fahrstreifenwechselassistenz. *In*: Hermann Winner, Stephan Hakuli und Gabriele Wolf (eds.): *Handbuch Fahrerassistenzsysteme: p.562-563;* Wiesbaden (Vieweg+Teubner Verlag)

[5] Fitch G. M. et al. (2011): *Analysis of Lane-Change Crashes and Near-Crashes*. Springfield, Virginia (US Department of Transportation)

[6] James H. et al. (1992): *The Dictionary for Human Factors/Ergonomics*. Florida (CRC Press, Inc.)

[7] Johannsen, Gunnar (1993): *Mensch-Maschine-Systeme*. Berlin (Springer-Verlag)

[8] Kebeck, Günther et al. (1997): *Vergessene Ergonomie : gedächtnispsychologische Aspekte der Gestaltung von Displays*. Münster (Lit)

[9] Abendroth, Bettina et al. (2012): Die Leistungsfähigkeit des Menschen für die Fahrzeugführung. *In* Hermann Winner, Stephan Hakuli und Gabriele Wolf (eds.): *Handbuch Fahrerassistenzsysteme: p.4-12;* Wiesbaden (Vieweg+Teubner Verlag)

[10] RESPONSE 3 (2009): *Code of Practice for the Design and Evaluation of ADAS*. PreVent project, www.prevent-ip.org, 2009.

[11] Knoll, Peter (2010): Motivation für den Einsatz von Fahrerassistenzsystemen. *In:* Reif, Konrad (eds.): *Fahrstabilisierungssysteme und Fahrerassistenzsysteme: 109;* Wiesbaden (Vieweg+Teubner Verlag)

[12] Plavšić, Martina (2008): Problematik der Fahrerassistenzsysteme und Rolle der Fahrmodellierung. *In:*Heiner Bubb (eds): *Ergonomie aktuell;* Garching (Lehrstuhl für Ergonomie)

[13] Fastenmeier, Wolfgang (1995): *Autofahrer und Verkehrssituationen ; Neue Wege zur Bewertung von Sicherheit und Zuverlässigkeit moderner Straßenverkehrssysteme*. Hartmut Häcker (eds.); Bonn (Deutscher Psychologen-Verlag)

[14] Gasser, Tom et al. (2012): *Rechtsfolgen zunehmender Fahrzeugautomatisierung: Gemeinsamer Schlussbericht der Projektgruppe*. Bundesanstalt fur Strasenwesen (eds.); Bremerhaven: (Wirtschaftsverlag NW)

[15] Bruder, Ralph et al. (2012): Gestaltung von Mensch-Maschine-Schnittstellen. *In:* Hermann Winner, Stephan Hakuli und Gabriele Wolf (eds.): *Handbuch Fahrerassistenzsysteme: p.336;* Wiesbaden (Vieweg+Teubner Verlag)

[16] DIN EN ISO 894-1. (2009): *Sicherheit von Maschinen-Ergonomische Anforderungen an die Gestaltung von Anzeigen und Stellteilen-Teil 1: Allgemeine Leitsätze für Benutzer-Interaktion mit Anzeigen und Stellteilen*. Berlin (Deutsche Norm)

[17] Knoll, Peter (2012): Anzeigen für Fahrerassistenzsysteme. *In:* Hermann Winner, Stephan Hakuli und Gabriele Wolf (eds.): *Handbuch Fahrerassistenzsysteme: p. 331*; Wiesbaden (Vieweg+Teubner Verlag)

[18] Endsley, M.R. (1995): Toward a Theory of Situation Awareness in Dynamic Systems. *In: Human Factors: The Journal of the Human Factors and Ergonomics Socienty, 37*, p. 32-64.

[19] Wickens et al. (2003): *Introduction to Human Factors Engineering*. New Jersey (Pearson)

[20] Sarter, N. B., and Woods, D. D.(1995): How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Human Factors, 37(1)*, p.5-20

[21] Norman, D. A. (1983): Some Observations on Mental Models. *In*: D. A. Gentner & A. L. Stevens (Eds.), Mental Models. Hillsdale, NJ: Lawrence Erlbaum.

[22] Kolbig, Maria et al. (2013): Mode Awareness im Fahrkontext: Eine theoretische Betrachtung. *In:* Elisabeth Brandenburg, Laura Doria, Alice Gross, Torsten Günzler, Hardy Smieszek (eds.): *Grundlagen und Anwendungen der Mensch-Maschine-Interaktion: 10. Berliner Werkstatt Mensch-Maschine-Systeme 10.-12. Oktober 2013: p1-8*; Berlin (Technische Uni Berlin)

[23] Gruhn, Paul (2011): Human Machine Interface (HMI) Design: The Good, The Bad, and The Ugly (and what makes them so). Houston (ICS Triplex | Rockwell Automation)

[24] Burmester, Michael (2008): Usability- Der Mensch im Fahrzeug. *In:* Ansgar Meroth, Boris Tolg (eds.): *Infotainmentsysteme im Kraftfahrzeug: p.321-351;* Wiesbaden (Vieweg & Sohn Verlag)

[25] European Commission (2005): *European Statement of Principles on the Design of Human Machine Interaction*. http://www.imobilitysupport.eu/, accessed: 25.11.2014

[26] König, Winfried (2012): Nutzergerechte Entwicklung der Mensch-Maschine- Interaktion von Fahrerassistenzsystemen. *In:* Hermann Winner, Stephan Hakuli und Gabriele Wolf (eds.): *Handbuch Fahrerassistenzsysteme: p.33-42;* Wiesbaden (Vieweg+Teubner Verlag)

[27] DIN EN ISO 9241-12 (1996): *Europäisches Komitee für Normung, Ergonomische Anforderungen für Bürotätigkeiten mit Bildschirmgeräten. Teil 12: Informationsdarstellung 1996-07*. Berlin (Deutsches Institut für Normung)

[28] Henning, Matthias (2010): *Preparation for lane change manoeuvres: Behavioural indicators and underlying cognitive processes.* Fakultät für Human- und Sozialwissenschaften der Technischen Universität Chemnitz.

[29] Chovan, John D. et al. (1994): *Examination of Lane Change Crashes and Potential IVHS Countermeasures*. U.S. Department of Transportation. National Highway Traffic Safety Administration

[30] Knoll, Peter (2010): Motivation für den Einsatz von Fahrerassistenzsystemen. *In:* Reif, Konrad (eds.): *Fahrstabilisierungssysteme und Fahrerassistenzsysteme: p. 116;* Wiesbaden (Vieweg+Teubner Verlag)

[31] Herczeg, Michael (2009): Software-Ergonomie: Theorien, Modelle und Kriterien für gebrauchstaugliche interaktive Computersysteme. Munchen (Oldenbourg)

[32] Schoitsch, Erwin et al. (2012): Lane-Sensitive Positioning and Navigation for Innovative ITS Services. In:Jan Fischer-Wolfarth, Gereon Meyer (eds.): *Advanced Microsystems for Automotive Applications 2012: p. 296-279;* Berlin, Heidelberg (Springer)