ADAS for the Car of the Future

Interface Concepts for Advanced Driver Assistant Systems
in a Sustainable Mobility Concept of 2020

Design Report

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Preface

The main reason why I got interested in this project and the assignment was a previous Industrial Design research assignment about autonomous vehicles. The knowledge gathered for that assignment could be useful for this new project. One of my personal objectives was to keep the theoretical research limited to a small literature research, and then spend most time on sketching and designing new concepts.

After working on the assignment for a while, it was found impossible to limit the theoretical research. A lot of aspects of the assignment had to be considered in order to end up with a feasible concept design like I'd like it to become. This is the reason that the majority of this design report describes introductory research and analysis, before getting to the concept design chapter.

Though the personal objective wasn't reached, I'm pleased with the result. I think it does provide a pretty feasible and well thought-out collection of concepts which may actually be used in the Car of the Future someday.

Jos Thalen

Enschede

August 25, 2006

Abstract

"ADAS For the Car of the Future"

Interface Concepts for Advanced Driver Assistant Systems in a Sustainable Mobility Concept of 2020

Background - Intelligent Vehicle Systems offer great potential to future mobility. An increase of intelligent in-vehicle applications may improve safety and provide comfort. Several sources indicate the benefits of Advanced Driver Assistance Systems and other Intelligent Transportation Systems to be significant. For the Car of the Future, a concept development challenge initiated by the Dutch Society for Nature and Environment, it's therefore vital to be equipped with these systems. It can improve the active safety aspects of the vehicle, and make the car more attractive to buy and use.

Methods & Results - The first part of the research is based primarily on literature. A state of the art of ADAS is presented, as well as an overview of ADAS related research projects. Several ADAS systems, such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW)and Intelligent Speed Assistance (ISA) are already popular among car manufacturers, or are being developed.

To try and integrate a selection of these systems into a single integrated ADAS concept, a design approach has been defined. The approach splits the research into two main parts. The first part covers the design of an integrated ADAS system. The second part covers the design of interface concepts for the ADAS system.

System Concept

The first part, the design of an ADAS system started with the investigation of user and stakeholder requirements. It was found that drivers accept ADAS systems, as long as they keep a certain amount of control. To comply to these requirements, the system uses so called *system states.* Every system state offers a certain amount of control, leaving the choice with the driver.

To define which drive tasks were to be supported, a system analysis of current ADAS systems has been made. Functions of these systems have been integrated into new multi-purpose functions and components. The results offers the support of the future driver in both longitudinal and lateral direction, by combining functions of current systems like cruise control, lane monitoring and control, obstacle avoidance and speed assistance. Improving safety is the primary goal of the system. Other characteristics are its flexibility and adaptability in use, and sustainable component selection.

Interface Concept

In the second part of the research, an interface framework was designed. Interactions between the driver and system have been investigated and used to define information flows. Next, input and output channels have been defined, indicating which information is presented to the user (output for a particular system state) and which information is used as input.

For the resulting interface framework four concepts have been designed, differing in feasibility and 'fanciness'. These concepts were named *Classic, Adaptive, Futuristic* and *Road Assistant*, referring to their key features.

Conclusions & Recommendations - The research ended with evaluations of both the system concept and the interface concepts. As for the system concept, further research regarding law, workload management and sensor integration is required. For the interface design, the 'Adaptive interface' and the 'Road Assistant' concepts turn out to be most favourable for further development, based on system and interface evaluations.

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Project Introduction

The Dutch Society for Nature and Environment (SNE) initially proposed a challenge for the three Dutch technical universities to design a sustainable mobility concept for 2020. This proposal was reshaped into a design challenge for 3TU, which is an umbrella organisation for the universities of Delft, Eindhoven and Twente.

Conditions of the challenge include

- The car will remain a major form of transportation in 2020
- The sustainable society affects the car
- The infrastructure won't change drastically

3TU formed a group of students and counsellors, with the working title “Nexus”. This project group employs students to develop individual parts of the final mobility concept. For this group, the primary part of the mobility concept is the car, which is to become sustainable, silent, clean, safe and space efficient.

Assignment

The Nexus group uses a vision-driven design approach. A vision of the future is used to make design-related decisions. This vision includes social, economical and sustainability aspects. Taking a stand within this vision should result in a coherent and well thought-out resulting concept, containing the following *principles.*

- Structure
- Body
- Drivetrain
- Suspension
- **User Interface**
- **Active safety**
- Passive safety
- Framework

The University of Delft (TuD) focusses on the body and framework principles. This includes interior and exterior design, the definition of a user group, branding, concept framework, etcetera. The University of Eindhoven (TuE) is primarily working on the drivetrain and suspension of the car. For the University of Twente (UT) the main principles are user interface and active safety.

Project Approach

The goal of this research is to explore the implementation and development of so called Advanced Driver Assistance Systems[1] for the Car of the Future. Design oriented research is needed to find out which ADAS exist, and how they can be implemented in the concept car. The research will be divided into three phases.

1. The first phase includes a market analysis to give an impression of the available ADAS. Furthermore, the requirements and preferences of participants and users must be acquired by conducting stakeholders- and user analysis. The result of phase 1 will be an overview of available ADAS and a list of requirements and preferences of stakeholders and end-users.
2. During phase 2, combinations of systems will be designed and presented. When required, new ADAS solutions can be developed. Concepts will be presented to stakeholders using drawings and 3d models.
3. The concepts will be evaluated based on existing evaluation methods, and by using the system requirements defined during the research.

1 See Chapter 1 for a definition of ADAS

Report Structure

The three phases of this research are reported in this design report. The following chapters are used to present the research findings and developments.

- Chapter 1 includes a literature research report and an overview of available ADAS, prototypes and relevant research projects.
- Chapter 2 investigates the issues related to the development of an ADAS concept. It concludes with a proposal design approach.
- Chapter 3 describes the actual development of an integrated ADAS concept on system level, resulting in a system specification.
- Chapter 4 continues the system development, focussing on the user interface. In this chapter the interface concepts are presented.
- Chapter 5 concludes with the evaluation of the concepts, resulting in a set of conclusions and recommendations.

The conclusions of this research are meant for further use in the Nexus project.

1. Introduction to ADAS

A first introduction to ADAS. What is it, and why would we use it? A market analysis will give an overview of existing products and their functionality. Next, a look at research projects and field-test reports will give an idea of current ADAS developments.

1.1 In-car Electronics

Since its introduction, the concept of the car hasn't changed a lot. A car still consists of four wheels, an engine, propulsion and an interior. Obviously technology has improved since the first production car, but the basics of the invention are still the same. Until a few years ago this was also true for the interface of a car, usually a steering wheel, control pedals and a dashboard. Recent developments show that this is changing significantly. An increase of in-car electronics is found.

The car radio is an example of in-car electronics, the GPS navigation kit is a more recent one. Adding these systems serves different goals. Car radio was meant to entertain the driver and passengers, GPS navigation is meant as a navigational aid, and could be considered a comfort system. Generally, in-car electronics can be categorised into either one of three categories[2].

- *Information systems* provide traffic or situational information, in order to help the driver navigate or generally use his car. Examples are navigation systems and traffic information receivers.
- *Entertainment systems* provide entertainment with video, music or other multimedia or office applications. For example, the car radio and modern in-car DVD players.
- *Safety systems* enhance the safety of driver and passengers, either by actively supporting the driving task, or passively (in the background) supporting the car itself. Examples are ABS and ESP (background) and driver assistance systems like cruise control.

Interactions between two or more categories occur. For example, a car radio can be used as entertainment, but may also provide the driver with traffic information. The interactions between categories should be an important consideration during the further design and research on Advanced Driver Assistance Systems. The interface in particular should provide the user with means to safely use all three categories.

This research will primarily focus on the safety systems. In-car active safety systems are generally called Advanced Driver Assistance Systems, or ADAS. ADAS are in turn part of a technology called Intelligent Transportation Systems, or ITS. A clear definition of ADAS is stated as follows.

ADAS: Advanced Driver Assistance Systems have a direct supporting interaction with the driver or the driver task. Their way of support may vary from informative to controlling. ADAS operate from inside the car, but may be connected to external sources.

Why ADAS?

As said above, ADAS supports the driver performing driving tasks. As a result, the use of these systems may increase traffic safety, traffic efficiency and improve the sustainability of the vehicle. Another aspect, comfort, can also be improved by the use of ADAS, however, the focus and goal of ADAS development is usually safety improvement.

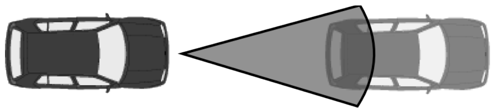
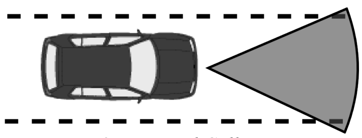
The implementation of ADAS (or intelligent transportation systems in general) may lead to a fatality decrease of 40%[3]. It's pointed out that new systems should be well designed and thoroughly tested before introduction.

The main goal of ADAS within this project is to improve future traffic safety. Although sustainability is influenced by the use of ADAS, it's too marginal to be used as a main objective. Nevertheless, sustainability effects, environmental factors and traffic efficiency will be taken into account during the research.

2 B.H. Kantowitz et al, 1999
3 B. van Kampen et al, 2005

1.2 ADAS Technology Overview

To give an impression of what ADAS means to end users, an overview of existing ADAS technology is presented. For convenience, they've been divided into subcategories. This short overview of existing ADAS technology only highlights the more 'common' types of ADAS. Other sources are available for a more complete list of available technology, see references[4],[5].

ADAS			***Description***
Longitudinal	ACC	Adaptive Cruise Control	ACC is becoming a more and more common accessory in modern cars. Basically, this technology keeps a safe distance between the driver's car and vehicles ahead. The driver can adjust the distance, and the system makes sure it's maintained, using throttle and brake control. Most ACC systems have influence on the driving task (they control brake and throttle), but still allow user take-overs.  *Fig 1: Adaptive Cruise Control*
	FCW	Forward Collision Warning	Like the ACC, this system detects vehicles in front of the driver's car. Obviously, it can be integrated with ACC. However, current systems still have problems distinguishing cars from trees, bridges from road signs, etc.  *Fig 2: Forward Collision Warning*
	ISA	Intelligent Speed Assistance	ISA influences the speed at which a car is driving. The maximum speed can be pre-set, or acquired from GPS data. Interfacing with the driver is done via the acceleration pedal, or by using visual or audio warnings.

4 L. Berghout, E. Versteegt et al, 2003
5 Stardust D1, August 2001

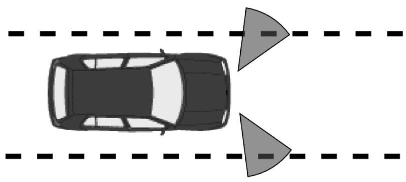
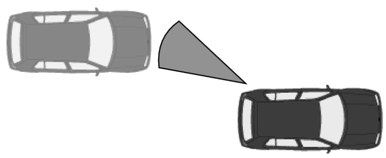
	ADAS		Description
Lateral Support	LDW	Lane Departure Warning	The main task of Lane Departure Warning is to make sure a car is driving safely between road marks (i.e. in a lane). LDW uses cameras and computer systems to detect and process roadsides and lane markings, and warn the driver if necessary. Acceptance of LDW is expected to be a problem because control of the car is given to the computer, and chances of false alarms are still present.
	LKS	Lane Keeping System	An extended version of the LDW system is the Lane Keeping System. Instead of warning the driver about the unintended lane departure, LKS intervenes with the driving task by using steering wheel actuators. LKS can completely take over the steering task of the driver.  *Fig 3: Lane Keeping System*
	LCA	Lane Change Assistance	LCA is a collection of technologies taking care of blind spots and rear-view problems. It uses sensors to detect objects and vehicles which normally can't be seen by the driver because of obstructed view. Also, approaching vehicles from behind can be detected in time, and the driver can be informed of this.  *Fig 4: Lane Change Assistance*
Miscellaneous		Night Vision Systems	These systems provide the driver with an enhanced view of the outside world. It's meant to be used during bad weather or night time. Though already implemented in several car models, the system still has a problem with its interface: how to present the enhanced image to the user. Current solutions consist of displaying the image on a monitor on the dashboard.
		Parking Assistance	The Parking Assistance system looks like Lane Change Assistance, but is meant for low speed and short distance, for example when parking a car. Using sensors a car can measure available space, and show this information to the driver. Current systems have limited use because of the low range these sensors operate with. Future developments will let the system take over control of the car during parking, letting the car park itself.
		Fuel Economy Devices	With Fuel Economy Devices the fuel flow and usage can be monitored and analysed per car. A system can intervene by informing the driver about the fuel usage, or by actively intervening, using an active gas pedal or other active systems.

Table 1: Basic ADAS technology overview

1.3 Development Projects

Three major stakeholders play a part in the development of ADAS technology, namely the government, research institutes and car manufacturers. Every stakeholder has its own objective with developing ADAS. The government is trying to solve traffic and safety problems. Research institutes work on experimental and innovative technologies, and car manufacturers are looking for improvements of their current fleet. Luckily, the three stakeholders often form cooperative development projects with specialised topics such as law, safety and technology. A list of relevant projects and a short description is given below.

ADASE

In Europe, a key project in ADAS development was ADASE (ADAS Europe). It's an umbrella organisation for about 30 sub- projects, covering technology, legal issues, ergonomics and psychology aspects. Using workshops and meetings, they let projects network together, working at the following goals:

- Harmonising and communicating active safety functions,
- Identifying technological needs and focussing on essentials,
- Preparing architectures, roadmap and standards.

Relevant sub-projects of ADASE are the RESPONSE projects. With RESPONSE, market possibilities are investigated thoroughly, resulting in detailed reports.

RESPONSE 1 (1999) concluded with a report[6] about ADAS technical specifications, user requirements and legal aspects. It concluded that there are no problems with introducing ADAS, as long as there's an option for the driver to take over control from the system. RESPONSE 2 (2005) elaborates on these results. With all aspects covered, a “Code of Practice” was written, meant to help with the design of ADAS.

The results of the ADASE project can be used to define a marketing strategy, and provide several guidelines for ADAS/ADAS HMI[7] design. Though useful, more recent projects should be investigated to determine the actuality of the ADASE project.

eSafety

The 2001 White Paper "European Transport Policy for 2010: Time to Decide" sets out the ambitious target of reducing the number of road fatalities with 50 percent by 2010. This requires a rapid increase in the efforts of all safety stakeholders. To support these actions, the European Commission officially launched the *e*Safety initiative in April 2002.

“eSafety brings together the European Commission, industry, public authorities and other stakeholders to accelerate the development, deployment and use of eSafety systems - Intelligent Vehicle Safety Systems - that use information and communication technologies in intelligent solutions, in order to increase road safety and reduce the number of accidents on Europe's roads.”[8]

Within this project, several workgroups are active in different areas. The Human-Machine Interface group[9] is most interesting for this research, as it's aiming at the design of HMI for Intelligent Vehicle Systems. At the moment, the result of this workgroup is a European statement of principles on Human Machine Interface, containing general design guidelines[10].

AIDE

The Adaptive Integrated Driver-vehicle Interface (AIDE) project is specifically working on the HMI aspects of ADAS implementation. Both ADAS and IVIS (In Vehicle Information Systems) are recognised as potential life savers. Furthermore, nomad devices[11] are expected to become more popular in cars. Their goal is to design an interface that safely integrates nomad devices, ADAS and IVIS. Several workgroups are defined, of which “Design and Development of an Adaptive Integrated Driver-vehicle Interface” is most relevant for this research. So far, results include scenario sketches, workshops and guideline-overviews. Because this project is still active, most reports are confidential and not

6 S. Becker, T. Johanning et al, RESPONSE, D4.2, v. 2.0, 1999
7 HMI: Human Machine Interaction
8 Quoted from the eSafety website
9 A workgroup of the eSafety project
10 See Chapter 2, paragraph 2
11 Portable personal devices such as a PDA, a mobile phone

accessible for this research.

Communicar

In the COMUNICAR project[12], an attempt has been made to develop a HMI for an in-car multimedia system. It was one of the first systems to integrate multiple in-car applications, from GPS navigation systems to other ADAS. The project recognised the potential mental overload, and found a solution by intelligently scheduling the information presented on screen. Information is presented when needed and when the traffic situation is safe enough.

Results from this approach can be used to design an improved version of this “information prioritising solution”. Also, time-taking usability tests taken during the research should be taken into consideration. Furthermore, practical knowledge of building in-car (software) prototypes is relevant during the prototyping phase of this research.

ADVISORS

The goals of the ADVISORS Project[13] in 2003 included (among others) to determine potentially successful ADAS, and test implementations of these systems by setting up pilot projects. The final report states that systems like ACC and ISA have the biggest potential. For each system, extensive risk and acceptance research has been done, which can be used in this research as well.

Furthermore, implementation strategies are discussed to determine how the ADAS should be inserted into the market. System integration and standardisation are found to be necessary for successful marketing. This is a responsibility for car manufacturers. Interesting remarks are also made with respect to positive government intervention.

1.4 Current ADAS Applications

This paragraph presents examples of current ADAS applications, as well as ADAS field test results. The examples form just a small selection.

Adaptive Cruise Control

ACC is found to be on of the most successful ADAS systems at the moment. It was one of the first systems to be built in frequently with modern luxury production cars, and becomes more and more popular among less expensive classes of cars as well.

- Mercedes S550: “Stop & Go” ACC
- Lexus LS430/460
- BMW 3,5 and 7 series
- Honda Accord ADAS
- Nissan Primera

Lane Departure Warning

LDW systems are less common among normal cars, but are quite often found in modern trucks and large vehicles. LDW decreases the chance of roll-over accidents, which most frequently happen with these kind of cars. Last years more and more luxury passenger cars are equipped with LDW systems.

- Nissan Infiniti FX and M45
- Honda Accord ADAS
- Citroen C4 and C5 infra-red LDW
- MAN Guard System
- Daimler-Chrysler Spurassistent
- DAF SafeTRAC system

12 “Summary of COMMUNICAR”, 2004
13 “ADVISORS final report”, 2003

Another ADAS technology that is implemented in large vehicles and trucks is the ISA system.

ACC Field Test

A field test with ACC was taken by the TU Delft in the Netherlands[14]. They test-drove a Nissan Primara equipped with ACC. Their findings were according to expectations, and generally not very positive. It's found that current ACC systems lack certain crucial functions, especially during overtaking situations. Problems mentioned with road curvature have been solved by more modern ACC systems.

The interaction with non-assisted vehicles is mentioned as one of the major problems of ACC (or ADAS' general) market introduction.

LDW Field Test

In Lelystad, the Netherlands[15], a large scale test with LDW systems was held. The objectives of this test were to determine the traffic flow and safety effects of LDW systems, and to let the public know about the existence of ADAS and LDW in particular. The LDW systems were installed in a fleet of buses and trucks.

General results are positive. The acceptance of ADAS and LDW is reasonably high, as test subject indicate to have used LDW 75 percent of their driving time on main roads. The effects of LDW on safety are found to be significant. LDW may cause a decrease in truck involved accidents of nine percent.

The test concludes with positive prospects, though it's noted that full implementation of LDW will take several years.

ISA Field Test

In Sweden, a large-scale experiment with the 'supportive' variant[16] was held. When the driver exceeds local speed limits, the gas pedal would resist with more pressure. However, the driver could overrule ISA by pressing down the gas pedal with more power. The experiment showed a decrease in speed, and a decrease in travelling time. The users reported they were driving safer (or at least feeling so) and smoother. On the other hand, they found driving to become less fun, and had a feeling of being watched all the time.

In Tilburg, the Netherlands, experiments with a mandatory implementation of ISA shows similar results[17]. ISA is recognised as a traffic safety improvement, however, there's a more negative attitude towards mandatory solutions compared to informing or or assisting.

General conclusion of the trials is that to achieve acceptance, the ISA should be of an advisory kind, and most effective in urban areas with maximum speeds of 30 to 50 km/h.

Other Systems

This overview does not mention driving assistance systems like ABS (Anti Blocking System) or ESP (Electronic Stability Program). The reason for this is that these systems are presumed 'standard' in the 2020 future, and they don't have a direct interaction with the driver.

14 H.M. Jagtman et al, 2003
15 Dutch Ministry Traffic and Water management, August 2001
16 http://www.isa.vv.se/cgi-bin2/dynamic.cgi?page=39&lang=en
17 J.H. Kraay, 2002

1.5 Conclusions

Summary

Advanced Driver Assistance Systems have been introduced, as well as the meaning of ADAS within this project. The safety effects of ADAS are expected to be significant, but ADAS may also offer comfort and sustainability improvements.

A literature based overview of existing ADAS was made. The overview shows a variety of systems, divided by their functionality. It's found that the main categories are longitudinal and lateral support. For longitudinal support, systems like Adaptive Cruise Control, Forward Collision Warning and Intelligent Speed Assistance are available. Lane Departure Warning, Lane Change Assistance and Lane Keeping Systems provide lateral support.

Several of these ADAS systems, like ACC, ISA and LDW, have already found their way into both passenger and transport vehicles. This indicates the great potential of the systems mentioned above. Therefore they should be considered for implementation within this project.

Several projects are working on research and implementation of ADAS in the current and future market. In Europe, RESPONSE and eSafety play an important role. Funded by the EU, eSafety covers several sub-projects, of which AIDE is most interesting for this research. These and other project reports will be used during the design/concept phase of this research.

Prototypes of ADAS and field test results have been discussed. It becomes clear that the future of ADAS is bright, but certain development and implementation aspects need further investigation. Acceptance is a major issue often referred to in projects and field test results.

Interpretation

The chapter provides two main conclusions.

Firstly, the fact that ADAS systems like ACC, LDW and ISA are already being used in production cars indicates that they also have a high potential for this project. Though other systems should also be considered, ACC, LDW and ISA deserve priority at least.

Secondly, the problematic development and implementation aspects, such as acceptance, need to be investigated further. By looking at these problems more thoroughly, they can be taken into account during the design stage.

The next chapter will use these conclusions to define a development approach for the system concept.

2. Design Approach

The goal of this chapter is to define a development approach for the design of an ADAS system concept. The first step is to further investigate the research area, including development aspects mentioned in Chapter 1. After looking at these aspects, an appropriate development approach can be defined.

2.1 Research Area

The main goal of this research is to investigate which ADAS systems may be used in the Car of the Future in 2020. As shown in Chapter 1, several ADAS systems are available or being developed. Based on these results, it's decided to design a system that combines functionalities of several ADAS systems. After designing this underlying system a user interface has to be designed.

The research area therefore consists of two major parts, namely the design of the underlying system, and the design of the user interface. For future reference, the underlying system will be called '*system concept*', the user interface will be referred to as '*interface concept'*.

An approach is needed to define how the system and the interface will be developed. In preparation to this approach, known development problems regarding the system concept and the interface concepts need to be investigated.

2.2 Known Problems

For the system concept, some problems have already been mentioned in Chapter 1, and will be dealt with more thoroughly here. For the interface concepts, problems are generally caused by lack of proper guidelines.

Problems Regarding the System

Chapter 1 already mentioned the introduction and acceptance aspects. The following list includes all major problematic aspects of ADAS development.

1. Introduction / Acceptance
2. Negative behavioural changes
3. Workload / driving task effects

1. ADAS Introduction & Acceptance

The success of Adaptive Cruise Control proves there's a market for ADAS products. However, users should be approached with care and patience, according to literature[18]. In 2001, the RESPONSE project concluded[19];

"[…] the market introduction of ADAS shall be evaluated as not problematic as long as the driver is in a position to control and override the systems. A change in scenario occurs when this is not the case. This significant fact may inhibit the market introduction of ADAS."

Research undertaken for the Highway Agency (GB) in 2001confirms this conclusion[20] . The report describes a general positive attitude towards in-car electronics, particularly the information systems. Automated control systems are found to be less popular. It also noted a difference of acceptance between men and women. Men tend to reject the system to take over control, while women (as well as elderly people and people not interested in new technology) accept control being taken away. This research did not focus on specific types of ADAS, but made a division into information systems, driver assistance systems and fully automated highway systems.

A more recent survey among internet users went more into specific ADAS, and confirms the findings mentioned above[21]. Also, the RESPONSE 2 final report[22] states that for successful market introduction, the focus should first be on safety oriented ADAS which have proven their effectiveness.

18 Brookhuis et al, 2001
19 S. Becker, T. Johanning et al, RESPONSE, D4.2, v. 2.0, 1999
20 Chalmers, 2001
21 van Driel et al, 2005
22 E. Donner, H. Schollinski et al, RESPONSE 2 Final report D1, 2004

2. Negative Behavioural Changes

Presuming ADAS will eventually be accepted by the public, possible negative changes in driver behaviour are expected. These changes are studied and mentioned frequently in several research reports. The following factors have been found to cause negative driving effects[23].

- *Context Factors* - One factor that influences the behaviour of the driver is the user environment. This includes the road, signs and other vehicles. For example, the decision to activate ISA appears to depend on surrounding vehicles; if everyone drives too fast, a driver will not activate ISA. Furthermore, if the activation of an ADAS significantly changes the behaviour of the vehicle, the driver is likely not to use it. Another context factor consist of other 'non-assisted' vehicles. Both positive and negative changes are found in the interaction between assisted and non-assisted drivers.
- *Individual Factors* - Driver behaviour also depends on the driver's personality and character. The personal driving style of an individual influences the acceptance of a system and the way of interacting with it. Usually styles are described like 'slow and by-the-book' and 'fast and furious'. For example, fast drivers turned out to drive faster with ACC in comparison with slow drivers with ACC.
- *Learning Time* - The driver has to adapt to the system, and learn how to use it. During this learning period the driving behaviour changes, as the driver has to experience how and when the system works. It's found to be important to inform the driver about the system's limits and capabilities to prevent over-reliance.

3. Workload / Driving Task Effects

Workload describes the amount of mental stress a driver experiences while performing his driver task. For example, workload may increase when crossing a busy intersection or when entering a highway. Workload is relatively low while cruising a low-traffic highway with constant speed. Performing multiple tasks at the same time tends to increase workload.

A theory describing the causes and effects of multitasking by humans is Wickens' Multiple Resource Theory. The attention and performance of the human brain is divided into separate specific parts, each part handling for example visual tasks or verbal tasks. According to the theory, workload can be reduced by offering information in three different states (early or late processing), modalities (auditory or visual) or codes (spatial or verbal). Multiple tasks can be performed without decreasing quality, as long as they are offered for example in a combination of visual and verbal tasks. In case of the driver, a secondary task like talking to an on-board computer can be performed while maintaining safe longitudinal distance and lateral position.

Considering that ADAS is only a small segment of the future in-car electronics (information and entertainment systems being the other ones), the average workload for future drivers may increase due to increasing amounts of information.

To solve workload related problems, research and development of so called workload managers is carried out. A workload manager can assess both external and internal relevant factors, such as the outside traffic, and the user workload. With this workload estimation, the system can prioritise information and safely present it to the user.

Several systems are already in use, or in an advanced stage of development. Examples are the Motorola Driver Advocate System[24] and the Delphi Driver Workload Manager[25]. It's found that several methods of workload measurement are used.

- External situation assessment
- Driver Physical Condition
- Driver's motions (eyes and hands)
- Driver's voice

There's no clear evidence as to which method works best.

23 K. Brookhuis, 2001
24 http://prwire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/01-05-2004/0002083138&EDATE=
25 http://www.delphi.com/news/solutions/monthly/ms54500-09082005

Problems Regarding the Interface

The design of a user interface relies heavily on the underlying system. This system provides the interface with a challenge, namely to let the user cooperate with or use the system. The interaction between user and system involves different fields of science, which makes interface design a challenge. In order to assist the interface design, several guidelines are available.

Guidelines may be defined by governments, scientific institutes or manufacturers. Their contents may range from general guidelines to specific prescriptions for a certain product.

Several sets of guidelines have been found and investigated for use within this research. By analysing these guidelines it can be decided whether or not to use them, and where in the design process they should be used, thus preventing common interface design flaws.

European Statement of Principles

The European Statement of Principles on the Design of Human Machine Interaction[26] is a EU-wide set of guidelines composed by experts, supporting the eSafety[27] project. As the name implies, the principles stated in this document are to be used as guidelines, not strict regulations. Several chapters cover most aspects of HMI design, from installation and design to usage and safety. Most of the guidelines are too generic to use directly during the design stage.

However, they could help pointing out areas of attention otherwise forgotten. For this research, most relevant chapters are chapter 3 through 5, covering “Information presentation principles”, “Principles on interaction with displays and controls” and “System behaviour principles” respectively. The guidelines apply to in-car information systems, which means they can't be applied to ADAS without further investigation.

EsoP Revision

The eSafety HMI workgroup also noticed the generic character of the EsoP, and proposed several important changes. On the whole, changes make the guidelines more specific by adding ISO regulations, and by addressing guidelines to specific stakeholders. The revision proposal document repeats the importance of differentiating between 'normal' information systems like navigational aids and ADAS. For the research in hand, (revised) guidelines from the EsoP can be used but should be checked for relevance with respect to ADAS.

US Statement of Principles

In the United States, a similar statement of principles is available[28]. The statement includes roughly the same chapters and topics as the EsoP, but contains more specifications. Though interesting to compare, it's decided to stick to the European revised statement. The revised European statement contains almost the same guidelines, with similar specifications.

General Interface Guidelines

Besides the mentioned guidelines, guidelines regarding automotive interface or general human machine interfaces are available. These guidelines contain more specified guidelines regarding the use of colour, shape and buttons compared to the other guidelines. A summary of such HMI/UI guidelines is presented in Appendix 4.

The further use of these guidelines will be discussed in the next paragraph.

26 EsoP, 2001
27 See Chapter 1
28 Alliance of Automobile Manufacturers, Report v 2.0, April 2002

2.3 Design Consequences

After describing the known problems with system and concept design, it should be decided how to prevent these problems from occurring.

ADAS Introduction & Acceptance

The first problem, regarding introduction and acceptance, has no direct consequences. As the projects aims at 2020, problems with introduction are beyond the scope of this research. It's presumed that most introductory problems as well as acceptance problems occur during the first few years of ADAS implementation. The analysis of this problem does point out another important aspect of ADAS. The way in which ADAS intervenes with the driving task turns out to play an important role in getting people to use the system. It's found that most people aren't willing to hand over control completely, with the exception of emergency situations. This aspect should be taken in account during system design.

Negative Behavioural Changes

The second problem, regarding negative behavioural changes, can be dealt with by deriving system design requirements from the problem description. For example, the problem description states that over-reliance may cause unsafe use of the system. A derived requirement would be to let the system always show its functional limits. The following list shows which requirements have been derived from the problem description.

- The ADAS system should not change the behaviour of the vehicle significantly, unless necessary
- The ADAS system should cooperate with non-assisted vehicles
- The ADAS system should intelligently adapt to the driver's character, within safety limits

These requirements should be incorporated in the general system requirements, which will be defined in a later stage of the design.

Workload/ Driving Task Effects

The problem considering workload and driving task is very relevant. Current research usually discusses a situation where there's a primary task (i.e. driving) combined with secondary tasks like using an in-car phone, or operating in-car computers[29]. The general conclusion of this literature is that multitasking doesn't promote safety. So the way ADAS is implemented affects the driver workload. In contrary to phones and navigation systems, ADAS shouldn't be implemented as an 'additional system' but rather as a background primary safety system. This prevents ADAS from taking up even more driver attention, as ADAS becomes part of the driving task.

Though playing a background role, the ADAS system should be visually present and available for input and output. This way the driver may also decide to let ADAS take a more controlling role, leaving time available for secondary systems. For example, when the phone rings, and the driver decides to answer it ADAS may take over lateral vehicle control to increase safety.

Interface Consequences

The presented interface guidelines differ in their applicability for this research.

The revised EsoP contains a valuable list of aspects that may otherwise be overlooked during the design. However, using this list in the early stage of design is useless, as there is no clear vision of what the system should do exactly. Therefore it's decided to use the revised EsoP as a set of evaluation aspects. By evaluating early stage concepts, forgotten aspects can be added, while other aspects may be improved.

The general interface guidelines regarding the use of colours, shapes and different modalities will be used after global interface concepts have been designed. At that stage it's clear which concept is going to use which modality, and which interface guidelines apply. As the concepts evolve, the guidelines can be used to further detail the design of displays, sound messages, etcetera.

So on the whole, the guidelines will be used in the later stage of development, where they may serve as design evaluation methods, and assist in further designing concepts.

29 P. Green, 2004

2.4 Design Approach

Now that the research area and the problematic aspects of ADAS design have been discussed, a design approach can be defined. The results of the previous paragraphs will be considered during the phrasing of this design approach.

As said, the research area contains two major parts, the system design and the interface design. The design approach however, will combine these two aspects in a single approach. As a basis of this approach, an existing method called the RESPONSE Checklist is used.

RESPONSE Checklist

The RESPONSE Checklist[30] is meant to be used in the early design stage, and aims to design with a user-centred approach. The checklist contains an A-part, which should lead to a detailed system specification. In this section, a standard design approach is described, from user analysis to system requirements. Part B of the checklist consists of a set of questions, meant to evaluate the resulting system.

Part A

The list describes a standard systematic design approach, starting with user definition and requirements (I/II), to system functions (III/V) and specifications (VI/XII). The following table presents all the covered aspects of the RESPONSE Checklist, part A.

I. System Users	VII. Compliance to Standards and Traffic Law
II. Encountered User Need	VIII. Situational Boundaries
III. Supported Task	IX. System Failures
IV. Functional Description	X. Product Information
V. Level of Automation	XI. Maintenance
VI. Human Machine Interface	XII. System Price

Table 2: Part A of the Response Checklist

Because of time restrictions and lack of relevance, certain aspects can be omitted. Only items in bold type will be taken into account, because of the following reasons.

The first four steps (I/IV) are necessary to define at least a basic system, which is required to reach the goal of this research. This includes the definition of users, their needs, as well as the task and functions the system is supposed to carry out.

The relevance of the level of automation (V) was already mentioned in the previous paragraph, and should be taken into the design approach. However, it's found unnecessary to point out 'Level of Automation' as a separate design aspect. Therefore it's decided that this aspect should be added to the 'Functional Description'.

The Human Machine Interface design (VI) concerns the design of the interface, and obviously very important for this research.

The other aspects, (VII/XII) are less important, as they do not significantly affect the main goal of this research, which is to design an ADAS interface. Their influence is too marginal, so available time will be spent on the more important aspects.

30 M. Kopf, P. Allen et al, RESPONSE Checklist, 1999

Part B

After filling out Part A of the checklist, a system specification is at hand. The (theoretical) effects of this specification can be evaluated. The list provides a collection of 'evaluation concepts', by means of which the system should be evaluated. As with part A, certain evaluation concepts can be omitted due to time restrictions or relevance[31].

1. Perceptibility
2. Comprehensibility
3. Learnability
4. Predictability
5. Controllability
6. Behavioural Change
7. Microscopic Traffic Safety
8. Macroscopic Traffic Effects
9. Driving Economy
10. Workload/Fatigue
11. Vigilance
12. Error Robustness
13. Emotional Issues
14. Trust
15. Responsibility
16. Driving Efficiency

Table 3 - Part B of the Response Checklist

A selection of relevant evaluation concepts can be used to find relevant questions in Part B of the checklist. This is done using a matrix system with questions vertical, and evaluation concepts horizontal. This method is used and described in Chapter 5, where the resulting ADAS concept is evaluated with the help of the checklist part B.

31 This will be explained in the system evaluation presented in Chapter 5

Design Approach

The selected aspects of the Checklist part A are used to set up the final design approach. It's decided to divide the design approach into three phases.

The first phase covers the user analysis, where users and user needs are defined. The 'System Users' and 'Encountered User Need' aspects of the Checklist are implemented here.

The next phase uses the results of phase 1 to decide which systems are needed to fulfil the needs of users. This phase includes aspects 'Supported Task', 'Functional Description' and 'Level of Automation' of the Checklist.

Phase 3 concerns the development and design of a user interface.

Phase 4 concludes the approach with an evaluation of both the system concept and the interface concept. Part B of the Checklist can be used for this purpose. Also, the guidelines mentioned in 2.3 can be applied in this stage of the design.

1. User Analysis

I. System Users

II. Encountered User Need

2. Systems Definition

III. Supported Task

IV. Functional Description

3. Interface Design

VI. Human Machine Interface

4. System s Evaluation

This approach will be applied in the following chapters. The following diagram graphically describes the design approach, and will be used to indicate which phase of the design approach is being discussed. The objected goal of each phase is presented below the black arrows.

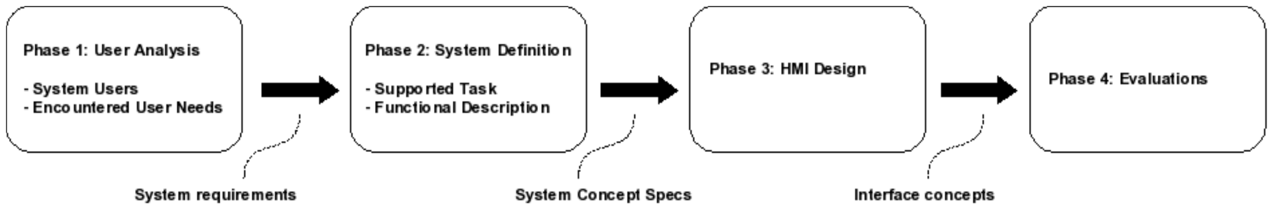


Fig 5: Graphical presentation of the design approach

2.5 Conclusions

The goal of this chapter was to define a design approach. The first step towards an approach was to define a research area, indicating the goal of the approach. It's been found necessary to design both a global *system concept* and an *interface concept*. The system concept is required for the proper design of an interface.

For the system concept, problems regarding the following are expected.

- Problems with introduction and acceptance, which are considered to be less relevant for the 2020 future of this project. However, the fact that 'level of automation' influences the acceptance of an ADAS system is pointed out as important.
- Negative Behavioural Changes are expected to appear after the introduction of ADAS. These changes have been analysed, and will be taken into account later on.
- Workload and driving task related problems; It's concluded that the role of ADAS in future cars should be so that ADAS takes a background safety role, not requiring active driver attention. A so called *“workload manager”* should be further developed to control the workload of the Car of the Future.

For interface design, it was found that problems may be prevented by designing according to the appropriate guidelines. Several guidelines have been discussed, and it's decided to use them during a later stage of the design, to assist in evaluating the concepts.

The problems regarding the system concept, as listed above, have their consequences on the design and the design approach.

- The 'level of automation' issue was made part of the 'Functional Description' in the design approach. This means that the system concept requires a function that fulfils the driver's requirements regarding the level of automation.
- The 'negative behavioural changes' issue was translated into a set of preliminary system requirements.
  - The ADAS system should not change the behaviour of the vehicle significantly, unless necessary
  - The ADAS system should cooperate with non-assisted vehicles
  - The ADAS system should intelligently adapt to the driver's character, within safety limits
- The workload management problem is to be solved by integrating a workload manager into the system. Also, the role of ADAS within the vehicle has been defined in such a way that ADAS won't negatively influence the driving task.

After the discussion of these problems, a design approach for a global ADAS concept is proposed. For the approach the RESPONE checklist has been found fit for this purpose. Though some items have been left out, the main route of the checklist will be used in this project.

1. User Analysis
2. Systems Definition
3. Interface Design
4. Systems Evaluation

The next chapter will deal with phase 1 and 2 of this approach. The interface design and systems evaluation will be discussed in later chapters.

3. System Concept

This chapter deals with the first two phases of the design approach, the 'User Analysis´ and 'System Definition'. The user analysis involves the definition of users and their needs. This results in a set of system requirements.

The system requirements are used in the next phase, the 'System Definition'. In this phase, the requirements are used to determine which part of the driving task is to be supported by the system concept. A functional description will then define which functions are needed to perform that task, and which components may carry out those functions.

Phase 1 and 2 are presented in the diagram below, along with their objected results, indicated below the black arrows.

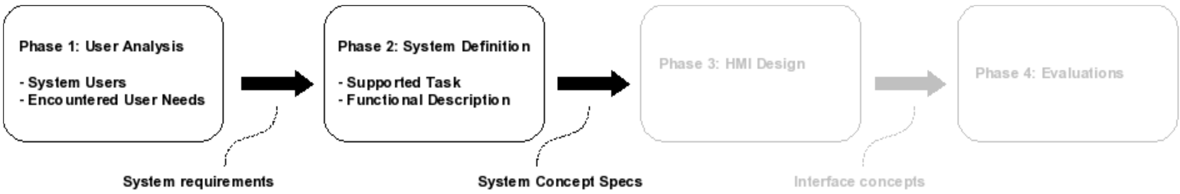


Fig 6: Phase 1 and Phase 2 of the design approach

3.1 User Analysis

The goal of the user analysis is to determine who the future system users are, and which requirements they have regarding the use of the system. The next paragraph will define the future user, and determine their needs. The 'Encountered User Needs' will translate the user needs into the objected system requirements.

System Users

Users are normally defined by concrete parameters such as income, age and sex. Based on these parameters user requirements are phrased. The Car of the Future project however, does not directly define a target group or users. Instead, a vision driven design approach is used. The Car of the Future vision contains assumptions and expectations with respect to the society, economy and mobility of 2020. So, an alternative approach is used to find the requirements.

Instead of looking for concrete user parameters, sources will be used to describe user *characteristics.* User characteristics will result in requirements and finally system specifications. The most relevant sources are literature (as used in chapter 1), the stakeholders opinions and the Nexus project vision. The following paragraphs will use these sources to extract concrete requirements .

Source I: Literature

In literature the following characteristics and requirements were already mentioned.

1. Users give priority to safety oriented ADAS[32]
2. Users are not willing to give away full control to ADAS[33]
3. Mobility users will include more older people[34]
4. Mobility users will include more females compared to present situation[35]

Table 4: User requirements and characteristics based on literature

32 See “Known Problems”, regarding “ADAS Introduction and Acceptance” on page 15
33 See “Known Problems”, regarding “ADAS Introduction and Acceptance” on page 15
34 See “Known Problems”, regarding “ADAS Introduction and Acceptance” on page 15
35 “Traffic & Water Management, 'Traveller of the Future' ”

These concluding requirements are the result of current research, and apply to a 'general public'. The objected user group of the Car of the Future is part of the general public, so these characteristics can be added to the total user image. Other findings from literature turn out to correspond to the ones found in the Nexus vision.

Source II: Nexus Vision

The vision of the Nexus project group is a wide perspective view on the 2020 future. It not only describes future mobility, but also links it to economy and society. The vision is to fit in a domain defined by the following restrictions.

- Time frame: 2020
- Initial location: Netherlands, Europe
- Using (adapted) current infrastructure
- Aiming at a sustainable solution

People in 2020 will use more means of communications in their social network. Due to modern communication, geographical boundaries will more or less disappear. More communication leads to bigger social networks. As 'personal contact' is still considered the highest form of interaction, people are expected to become more mobile as well as more individually oriented.

Both governments and consumers will recognise the shortage of resources. Sustainability is expected to become more (economically) attractive. An important shift from 'owning' to 'using' is foreseen. Other economic developments include the increasing use of external labour. In Europe, an increase of 'dedicated jobs' will be the result. People need to show their skills and abilities in order to be noticed. The Car of the Future is expected to help getting noticed. Another result is the need for people to be flexible and adaptable.

The car of the future is described as 'icon'. This means it should make distance irrelevant by absorbing the driver's attention. The car should also be an 'extended home', reflecting the user's abilities, skills, demands, etc. Social and economic aspects have changed the way people look at cars, and the car of the future should adapt to this change.

From these rather vague vision statements several user characteristics can be extracted. The following selection is considered relevant for the ADAS concept.

1. Users want to communicate
2. Users want to be mobile
3. Users become more individual
4. Users are interested in sustainability
5. Users are flexible and adaptable
6. Users want their car to be a reflection of themselves

Table 5: User requirements and characteristics based on the Nexus vision

Source III: Stakeholders

The Car of the Future project is affected by many stakeholders. Each stakeholder has its own preferences and requirements, priorities and influence. Several needs can be fulfilled by ADAS solutions. These needs are Safety, Comfort, Efficiency and Emotional Value, or combinations of those. Listing stakeholders and their needs will determine the 'character' of the concept. The following table lists all stakeholders, and their position with respect to ADAS.

The first column indicates the status of a stakeholder, divided into A, B and C-categories. Important and/or direct stakeholders are category A, irrelevant stakeholders are category C. The government, a B-category stakeholder, is most relevant during the introduction phase of ADAS. As this indirectly affects the 2020 future, this stakeholder is found relevant enough to be taken in to account.

	Stakeholder	Position
A	User	Users are willing to use the ADAS system. Safety is considered a priority reason for this, but shifts to comfort are expected as well, as safety becomes more and more 'standard'.
A	Non-user	Non users drive conventional cars, and are not willing or not able to use ADAS. This *could* have a negative effect on safety, and positive effects on emotional value, as there's always a need to distinguish among either users or non-users.
A	Nexus	Nexus' main concern is that the ADAS fits within their vision. Therefore it should have a positive appeal on the users emotional values.
A	SNE	SNE's main concern is sustainability. ADAS must have a positive effect on sustainability. Also, by positively affecting emotional values, marketing aspects for the car in general can be improved.
B	Government	During ADAS introduction, the government is expected to have positive influence on safety aspects. This results in positive influence on comfort, caused by shifting needs from safety to comfort.
C	Car manufacturers	Car manufacturers are only relevant during the production stage of this concept. The design process should take production aspects in account, but this does not affect any of the aspects mentioned directly.
C	Car salesmen	Car sales men do not affect the aspects directly, as they are expected to sell (or lease, according to the Nexus vision) whatever there's available/needed at the market.
A	Technology R&D	Technology R&D influences the character of the concept, because they provide the needed technology. Current developments tend to support safety. Comfort is also covered, but not by ADAS technology.

Table 6: Stakeholders and their position

The following table gives an overview of relevant stakeholders and their positive or negative influence on the concept character aspects.

Stakeholder	Safety	Comfort	Efficiency	Emotional Value
User	++	+		
Non-user	-	-		+
Nexus		+		++
SNE			++	+
Government	++	+		
Technology R&D	++	+		

Table 7: Stakeholders and their influences

It's shown that safety is a priority requirement, required by both users and government. Efficiency is only required by SNE, but should deserve more attention during the design phase, as SNE is a key stakeholder in this project.

Encountered User Needs

In the previous paragraph the characteristics of future users have been used to determine their needs and requirements.

Safety was more than once mentioned as an important aspect of ADAS. This requirement was also emphasised by the literature discussed in chapters 1 and 2.

The Nexus vision is treated as an important supplier of needs, so the needs for adaptability, flexibility and sustainability will also be taken in to account. Requirements like 'individuality' are harder to implement, nevertheless they should be remembered.

The following table presents the resulting set of requirements, to which the system concept is supposed to comply. In addition to the requirements derived from user needs, the table also includes the requirements proposed in chapter 2.

Requirement	***Requirement specification***
Provide Safety	The system should enhance the safety of the vehicle, within the limits of the project
	The system should not change the behaviour of the vehicle significantly, unless necessary
	The system should cooperate with non-assisted vehicles
	The system should support communications between users and vehicles
Provide Control	The system should let the user control ADAS influence
	The system should be adaptable by the user
Support Usability	The system should intelligently adapt to the driver's character, within safety limits
	The system should support drivers of all ages, within legal limits
	The system should support information and entertainment systems
	The system should support sustainability

Table 8: The system requirements, based on user needs

It should be noted that this table of requirements lists requirements for the global system. Some of these requirements apply to the *system concept*, while others apply to the *interface concept*.

This concludes the user analysis. It's been investigated who the future users of the system will be, and what their needs and requirements regarding ADAS are. The list of requirements can assist with the further definition of the system.

The following paragraph discusses the possibilities of the system concept, investigating which requirements can be fulfilled by the system concept. After this paragraph a reflection of requirements will be presented, giving feedback on how the system concept tries to fulfil requirements.

3.2 System Definition

As stated in the design approach., the system definition includes two aspects.

First, the ***'supported task'*** is to be investigated. This involves describing how the system should support the driver with his driving task. Needs and requirements, as presented in the user analysis, are used to determine which tasks should be supported, and when.

After defining this supporting task, the required systems need to be found, which is the goal of the ***functional description***.

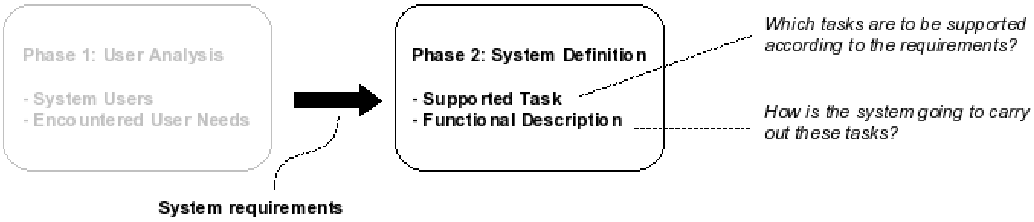


Fig 7: Phase 2, describing the system definition

Supported Task

One of the system requirements is to provide safety. Theoretically, stuffing the vehicle with control-computers may maximise traffic safety. However, this doesn't comply with the requirement of limited driving interference. There's a tension between fully automating a vehicle, and leaving control with the driver.

An aspect that adds to this tension is the variety of potential users. As stated above, the system should be usable for drivers of all ages. Users may vary from housewives to young businessmen. A proposed solution to this problem is to make the system adapt itself, based on the driver's characteristics. A certain amount of intelligence is required to achieve this. The system should be able to assess the driving capabilities and preferences of the driver, or should be able to get used to them. With that knowledge of the driver, the system can provide a specific way of support fitting the driver’s needs.

For example, someone may generally drive perfectly by the rules, but has a tendency to keep insufficient distance to cars in front. The system should notice this and inform or assist the driver. After a while, the support and information should decrease, in order to see whether the driver has learnt from it or not. If not, the system will regain support.

Overall, this means the system provides intelligent and adaptive, yet passive task support. At no point should the driver feel too much controlled or watched. The system should assist and support when necessary or preferred.

If the driver activates an autonomous function of the system, such as car following or lane keeping, the driver should constantly be informed about the fact that this system is working. Whether or not the driver is informed about the actions of the system depends on preferences, but at least the activation of the system should be indicated. Also, in case of problems, required intervention or deactivation the driver must be informed about this.

To implement this dynamic task support in the ADAS concept, it's decided to use so called system states.

System States

System states offer selected 'modes' of operations, each mode with its own characteristics. For this system, it's decided to use three main states, each one representing a certain amount of task support. The first state offers minimal support, and support increases as the level of state increases, as explained in the following state definitions.

State 1 - Informing

In state 1 the driver has complete vehicle control. The system will only *inform* the driver about unsafe situations, by warning and by giving safety advice. ADAS systems will only take over control in case of emergencies, like emergency brake situations, or when the driver is unable to respond.

State 2 – Assisting

In addition to the informing character of state 1, in state 2 the system *assists* the driver in driving more safely by correcting the steering wheel, throttle and brake systems. This state represents a midway between the current way of driving and autonomous driving.

State 3 – Controlling

This state is the autonomous driving state. Here the driver can let go the steering wheel and gas pedal, while lane keeping and throttle control systems take over. This state is only available under certain conditions. If it's not safe to drive autonomously, or even impossible, the system will indicate so.

Failure and Deactivation

The other two states are “Off” and “Failure”. In the “Off” state, the ADAS systems have been deactivated. This mode enables the driver to deactivate the entire system, or subsystems in case of failure or annoyance. For example, in urban environments certain ADAS may annoy the driver by causing too many false alarms.

The failure state is a system mode which can't be activated by the user, but is used whenever (critical) systems fail. The situation will be analysed and actions taken accordingly. The driver will be informed through interface output.

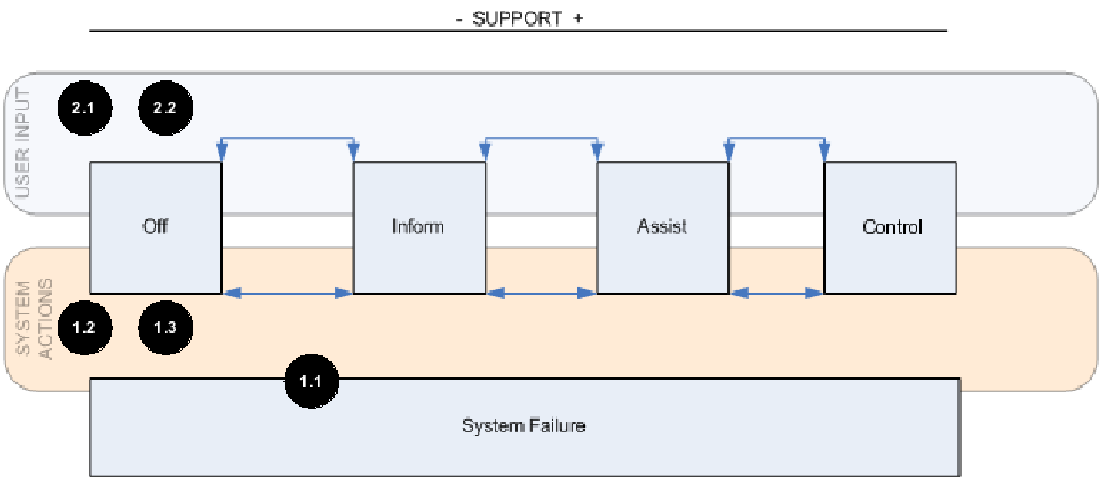


Fig 8: The system state diagram graphically presents the available states

State Transitions

Each state has a specific amount of active systems, providing a specific amount of support. As the state transition diagram shows (Fig. 4), transitions between the system states may either be caused by the system ('system actions') or by the user ('user input').

Transitions initiated by System

The system may initiate state transitions because of one of the following reasons.

1.1. *System failure* - If (essential) systems fail, the *failure state* should be accessed. In this mode the driver will be informed about malfunctions, and advised about what to do.

1.2. *Driver Attention problem* – Whenever the system detects a problem with driver attention, the amount of support increases, but only after asking the driver for confirmation. If a driver does not respond to a request, it's assumed necessary to intervene by increasing support. *(Shift to the left in the diagram)*

1.3. *Traffic Situation* – By using sensor input, the system can assess traffic situations, and determine whether it's needed to offer the driver additional support, for example, intersection support or cruise control. *(Shift to the left or right in the diagram)*

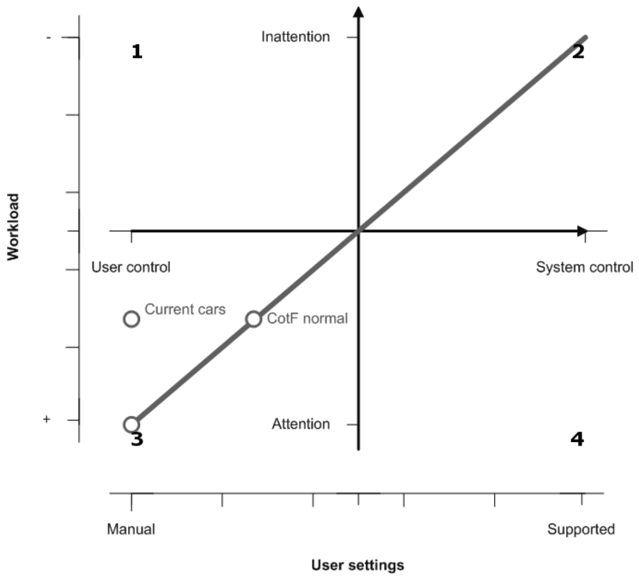
Transitions initiated by User

The driver may initiate state transitions because of one of the following reasons.

2.1 *Preferences* – If desired, the driver can hand over control to the system, leaving the driver with more time and attention for secondary tasks. Whether it's safe to take over control or not is up to the system to decide, based on traffic assessment. *(Shift to the left or right in the diagram)*

2.2 *General lack of driver attention* may cause the system to start taking over control, as defined in the system initiated state changes. *(Shift to the left in the diagram)*

The states can be used to further define the system character. They've been described graphically in the diagrams below. Horizontally, the amount of system control is presented, and vertically user attention. State 1 would be the default status, positioned in the lower left quadrant.



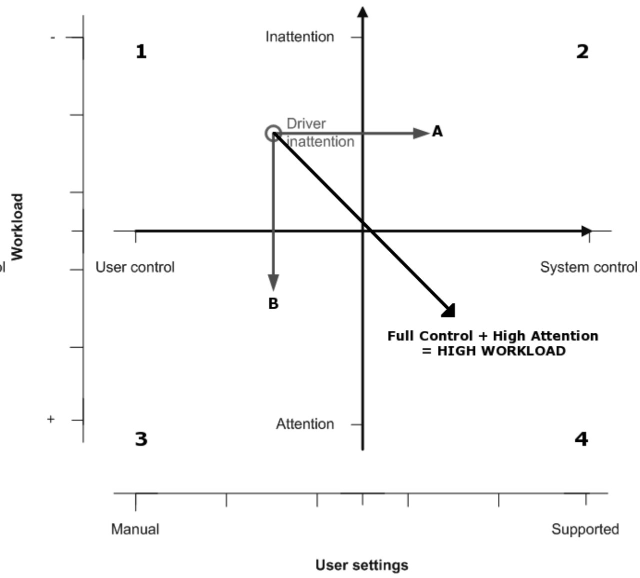


Fig 9: Graphical representations of system states (left) and state transitions (right)

The left diagram shows the system character of the Car of the Future in normal operation. The line indicates the preferred relation between driver attention and system support. If the driver is in control, system control should be minimal. With decreasing attention, system support should increase.

The right diagram shows an example of a state transition. At first, the attention of the driver is below usual value, while control is still in his hands (The circle in quadrant 1). The horizontal and vertical vectors indicate two available solutions. First, the system could take over control to regain safety (A). Second, user attention can be increased by following the vertical vector (B).

Choosing both solutions together , following the resultant vector, would end up in the fourth quadrant, which is not the best option as it may cause mental overload.

The definition of the system character and resulting system states provide additional system requirements. There's a need for both a driver assessment application and a traffic assessment application. The system needs to be able to see what the driver is doing, and assess the traffic situation.

Towards the Functional Description

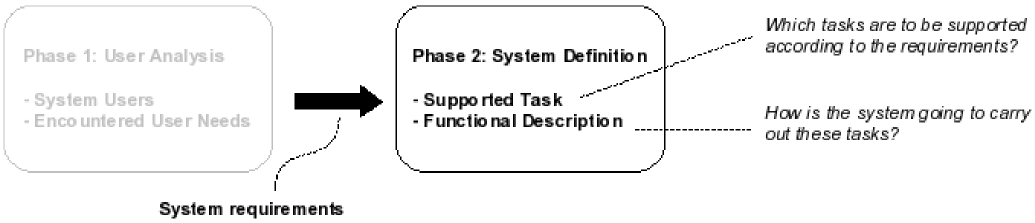


Fig 10: Phase 2, describing the system definition

The '*Supported Task'* paragraph found an answer to the question "Which tasks are to be supported according to the requirements". According to the system requirements ,users want safety, while staying in control of the vehicle. This tension between safety and control was solved by introducing system states. System states offer layered amounts of safety and control, and are user selectable.

Now it's up to the '*Functional Description'* to find out which systems may be used to provide the required safety and control. This will be done in the next paragraph.

Functional Description

The goal of the functional description is to determine which ADAS systems may fulfil the requirements and allow the task support defined in the previous paragraphs. A first step towards reaching this goal is to determine which systems are available around 2020.

Available Systems

To assess the availability of ADAS systems in 2020, a roadmap is sketched. The roadmap indicates which technologies are available within a certain period of time. Certain factors may influence the way in which ADAS may develop over the next few years, as listed below.

- Introduction & Acceptance, method of implementation
- The merging of intelligent traffic with 'normal' traffic
- Law may prevent ADAS from operating optimally

The resulting roadmap is based on the findings from chapter 1 and 2 as well as other ADAS road maps[36, 37]. The use of literature should increase the feasibility of the roadmap. Still, the following assumptions have been used during the making of the roadmap.

- Introduction and acceptance problems are limited due to the step-by-step introduction of ADAS
- ADAS systems are implemented as visible applications[38]
- Law is assumed to be adapted in favour of ADAS

As part of the integration aspect of this project, the roadmap also covers developments of information and entertainment systems. This table shows a basic roadmap. An extended version is presented in Appendix 1.

Time frame	*ADAS*	*Information*	*Entertainment*
2006-2010	- Use of ACC and ISA increase - ISA obligated in urban areas - Introduction of LDW in production cars	- Navigation systems on PDA's - Traffic information over radio	- Car radio, CD players, capabilities for mp3 playback, connection to mobile devices
2010-2015	- ACC advances to ACC+, longitudinal support advances (FCW) - Communications are advancing - Law adapts to allow ACC+ - LDW and other lateral support systems advance and become common	- Integrated navigation systems with traffic information systems - Higher level of information exchange through new communication methods	- Internet connectivity, improved ADAS provides more opportunities for multimedia, like DVD's and others
2015-2020	- Longitudinal and lateral support integrate - Car -to-car and car-to-infrastructure communications - Law adapted to allow these applications - Combination of assisted and non-assisted cars	- Information and navigation systems are linked to car control systems to provide a more integrated system.	- Autonomous driving provides even more opportunities for multimedia

Table 9: A basic ADAS roadmap from 2006 to 2020

36 http://www.publications.parliament.uk/pa/cm200304/cmselect/cmtran/319/319we47.htm
37 D. Ehmanns & H. Spannheimer, RESPONSE “Roadmap”, July 2004
38 Instead of being implemented as invisible applications, like ABS and ESP

The ADAS roadmap points out the expected available ADAS systems in 2020. These include longitudinal control and support systems like FCW, ISA and ACC, and lateral control systems like LDW, LKS and LCA. So which of these systems are to be used in the Car of the Future system concept?

Looking at the functional system requirements, it would be best to use all of the systems mentioned above in order to provide a maximum safety enhancement. In combination with the 'system states' this would provide an adaptable yet safe system to the user. However, restrictions should be taken in to account. The sustainability requirement may prevent certain systems from being used, as they decrease the sustainability aspects of the design because of high power usage.

Therefore the available systems need to be analysed to determine which task they fulfil, which functions they offer to do so, and what their component characteristics are.

System Analysis

A system analysis of ADAS and their components will give insights into their (sub) functionality and architecture. The analysis covers the following aspects.

1. A task analysis defines which part of the driving task is taken over by the ADAS. These tasks are divided into three main categories, being Stabilising, Manoeuvring and Navigating. This analysis helps to find the system functions.
2. A function analysis defines how the tasks (as mentioned above) are going to be executed by the system. A system may have one or more main functions, each one containing one or more sub functions.
3. A system outline shows all functions and sub functions of the system are drawn together in a diagram, indicating interactions between functions. The system outline gives an overview of the general working of the particular ADAS.
4. A component overview describes the actual realisation of system functions.

This analysis was carried out for all available systems, based on the roadmap outcomes, which are ACC, FCW, ISA, and lateral systems[39].

The main outcome of this series of analysis is a set of system functions. For every ADAS system, these functions can be used for either input, processing or output/reaction purposes. For example, an ACC system uses the functions listed in the second left column for input, processing and output.

	ADAS Systems and their functions				
	ACC	*LDW/LKS*	*ISA*	*FCW*	*LCA*
Input	Scan road Detect vehicles	Scan road Detect markings	Detect speed limit Detect current speed	Scan road Detect obstacles	Scan rear road Detect vehicles
Processing	Determine vehicle speed Determine local speed Calculate braking time Calculate following distance Acquire interface input	Predict path Detect deviations Calculate corrections Acquire interface input	Determine action Acquire interface input	Identify obstacles Determine action Acquire interface input	Determine risk Acquire interface input
Output	Provide interface output Apply brake Apply gear Apply throttle	Provide interface output Apply brake Alter steering	Provide interface output Apply brake Apply throttle	Provide interface output Apply brake Apply gear Apply throttle	Provide interface output Apply brake Apply steering

Table 10: An overview of ADAS systems and their functions

39 See Appendix 2

Several conclusions can be drawn from the table.

1. The system requires a connection to mechanical vehicle components. The throttle, gear, brake and steering wheel need to be controllable by the ADAS system. Also, systems like ISA require a connection to the speedometer.
2. Each ADAS system requires a user interface for both the input and the output of information. This is important to consider for the future interface design, as presented in chapter 4.
3. The system may use a single processing unit (CPU) to take care of all processing functions. A graphical processing unit is required for the processing of visual information.
4. An integration challenge can be found in the 'input' row of the table. The functions mentioned in this row are currently carried out by different sensors, so it's useful to see whether it's possible to use a single sensor for multiple purposes.

The first three conclusions result in clear concept requirements. They state that the concept should contain a CPU, a user interface and an interface to mechanical components. The fourth conclusion from the list will be clarified further below.

Sensor Selection

The upper row of the table indicates which functions are used as input for the ADAS systems. In order to design an integrated ADAS system, these functions need to be investigated for integration possibilities. The upper row shows that the forward 'scan road' function is used by four systems, namely ACC, FCW and LDW/LKS.

ACC	*LDW/LKS*	*ISA*	*FCW*	*LCA*
Scan road Detect vehicles	**Scan road** Detect markings	Detect speed limit Detect current speed	**Scan road** Detect obstacles	Scan rear road Detect vehicles

Table 11: Integrating system functions

Designing a new sensor that would fulfil the 'scan road' function for each of these ADAS systems is beyond the scope of this research. Therefore, existing and commonly used sensors have been investigated, as shown in the system analysis in Appendix 2.

It's concluded that the ACC and FCW systems can use the same forward looking 24 GHz radar. This radar will also provide backup for the LDW/LKS system, whose main sensor source will be a forward looking camera.

The LCA system has less integration possibilities, as it uses rear sensor systems instead of the forward looking radar and camera. Therefore it's decided that the LCA uses its own set of rear 24 GHz radar components. Furthermore, a communication device is needed for ISA to receive the local speed limit.

The following table summarises the applied sensors and their properties.

Component	*Capabilities*	*Power Consumption*	*Volume*
Forward 24 GHz radar	Max. 240m, 15° x 10° scanning field	+- 10 Watt	Data not available
Rear 24 GHz radar	Max. 15m, 30° scanning field	+- 3 Watt	60x45x30 mm³
Forward camera	Max. 30m, max 30° x -14° to 29° visual coverage	+- 7 Watt	200x100x50 mm³

Table 12: Sensor properties

Sensor Implementation

The implementation of the sensors results in two ways of task support. Firstly, there is longitudinal task support. Secondly, the system provides lateral task support. The new functions of the system concept have been correlated with these tasks so that the concept fulfils the tasks using functions as listed in the table below.

Longitudinal Functions		*Lateral Functions*	
Task	***Functions***	***Task***	***Functions***
Vehicle & Obstacle detection	Scan Road	Lane Tracking	Scan Road
Vehicle Tracking	Detect vehicle position Detect vehicle speed Detect vehicle distance Control Adjustments Warn HMI	Lane keeping/Warning	Detect markings Detect deviations Determine corrections Control Adjustments Warn HMI
Obstacle Avoidance	Detect obstacle position Warn HMI Control Adjustments	Rear Vehicle Detection	Scan read road Detect vehicle position Detect vehicle speed Control Adjustments Warn HMI
Speed Limit Detection	Detect speed limit Control Adjustments Warn HMI		

Table 13: Functionality of the system concept

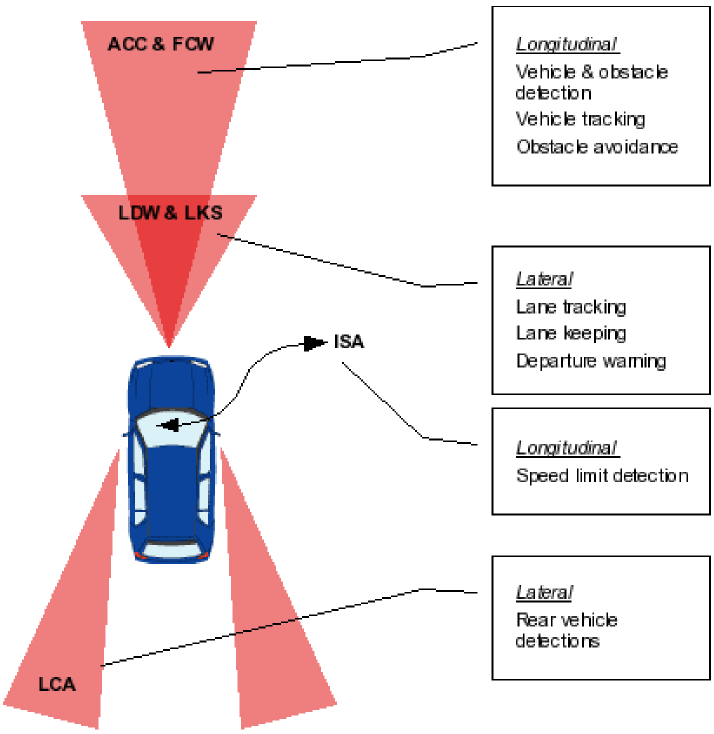


Fig 11: Graphical representation of the system functionality

3.3 System Concept

With the *functional description* concluded, it's possible to compose a final system concept. The functional description provides a set of conclusions that indicates which system components are required, besides the obvious sensors. These conclusions have been summarised and listed below.

1. The system requires a connection to mechanical vehicle components.
2. Each ADAS system requires a user interface for both input and output of information
3. The system may use a single processing unit (CPU) to take care of all the processing functions
4. The system uses a forward radar, forward camera, communication device and two rear radar systems as sensor devices[40]

Furthermore, Chapter 2 mentioned the need for a workload manager application, so this component should also be integrated with the system concept. The full design of a workload manager is beyond the scope of this research. However, a first step in the design of such a system has been included in Appendix 7.

Subsystems

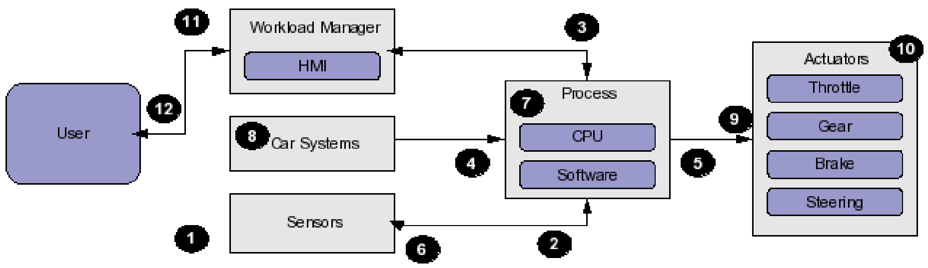
Based on these conclusions, several subsystems have been defined. The subsystems represent a group of components with a specific task or function. Besides the sensor subsystem, which has already been described in the functional description, the following subsystems are used.

- *Actuators* - Actuators directly control car components like steering, throttle and gear. For ADAS to operate, throttle, gear and steering should be controllable by those actuators[41]. Current engines are already fitted with computer control, and actuated steering shouldn't be a problem either.
- *CPU* - The CPU should be able to process constant real-time information, provided by sensors and car input devices. Furthermore, it may be necessary to use a specific graphical processing unit (GPU) for the forward looking camera device.
- *HMI/Workload Manager* - The workload manager needs to assess both the internal and external situation of the vehicle. The external situation can be received through the existing sensors, supported by car-to-car and car-to-infrastructure communications. The internal (workload) assessment can be done by using speech input or by watching the driver through a camera device.
- *Car Systems* - Car systems provide the ADAS concept with information about the engine, its status, fuel status, possible failures, vehicle speed, etcetera.

In practice, the driver won't directly interact with these functions. However, the *results* of these functions are very important for the driver. The results of the functions are for example the ability to track a preceding vehicle, or to automatically change lanes. In other words, these functions define the final functionality of the system concept, which are the safety supporting tasks[42].

The table on the next page shows the subsystem layout and their interacting functions.

40 Conclusion 4 has been altered, based on the results of the 'Sensor Selection' in the preceding paragraph
41 See “System Analysis” on page 32
42 See Table 13: Functionality of the system concept



Subsystem	Functions	Sub Functions
SENSORS	1. Receive sensor input	Receive forward radar image Receive forward camera image Receive speed limit Receive rear radar image
	2. Link to CPU	Send sensor input to CPU
CPU	3. Link to HMI	Receive input from HMI Send output to HMI
	4. Link to car systems	Receive input from car systems
	5. Link to actuators	Receive input from actuators Send output to actuators
	6. Link to sensors	Receive input from sensors
	7. Process	Process sensor input, car systems input, HMI input / output, actuators input/output, etcetera
CAR SYSTEMS	8. Provide input	Provide dynamics Provide engine status Provide fuel status Provide system status, etc.
ACTUATORS	9. Receive adjustments	Steering adjustments Throttle adjustments Gear changes Brake adjustments
	10. Actuate adjustments	Actuate steering Actuate throttle Actuate gear Actuate brake
WORKLOAD MANAGER/HMI	11. Receive user input	Receive vehicle controls Receive ADAS controls Receive other controls
	12. Provide user output	Provide ADAS output Provide vehicle systems output

Table 14: Subsystems and their appropriate functions and sub functions

Reflection of Requirements

The first paragraph of this chapter defined a list of requirements for the ADAS concept. After the detailed selection of systems and their properties, a short reflection of these requirements can be presented. The requirements have been listed in the table below, along with their implementation method in the system concept.

Requirement	Requirement specification	Implementation
Provide Safety	*The system should enhance the safety of the vehicle, within the limits of the project*	Longitudinal and lateral support functions
	The system should not change the behaviour of the vehicle significantly, unless necessary	The use of system states
	The system should cooperate with non-assisted vehicles	The system-concept is autonomous, operating independently from infrastructure
	The system should support communications between users and vehicles	The system uses a communication device for speed limit detection
Provide Control	*The system should let the user control ADAS influence*	HMI
	The system should be adaptable by the user	HMI
Support Usability	*The system should intelligently adapt to the driver's character, within safety limits*	System intelligence, HMI and workload manager
	The system should support drivers of all ages, within legal limits	HMI
	The system should support information and entertainment systems	HMI/Workload manager
	The system should support sustainability	The system uses several multifunctional components

Table 15: Requirements and implementations

The reflection of requirements shows how user requirements have been implemented in the system concept. The table also indicates which implementations are to be made through user interface design. These requirements should be taken into account in the next chapter.

3.4 Conclusions

This chapter describes the development of an integrated system concept for ADAS in 2020. It uses the design approach as described in Chapter 2.

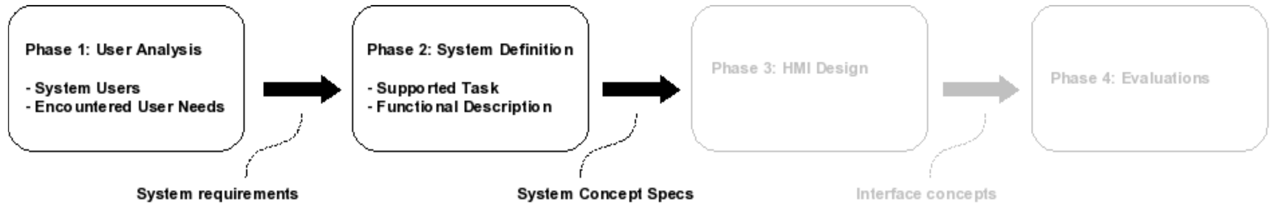


Fig 12: Phase 1 and 2 of the design approach

Phase 1 covered the *'user analysis'*. The goal of this phase is to acquire user needs to define system requirements. This was done using multiple sources, including the Nexus vision, literature and stakeholder analysis. The resulting requirements have been split in to functional requirements, usability requirements and package requirements.

The main functional requirement is that the system should improve safety. Usability requirements include the need for adaptability and system intelligence. Package requirements concern the sustainability and system integration aspect of the concept. These are the key requirements, other requirements have been listed in the table in paragraph 3.1.

The requirements that were defined in phase 1 are used in phase 2 (the *system definition)* to determine which part of the driving task is to be supported, and how to support it.

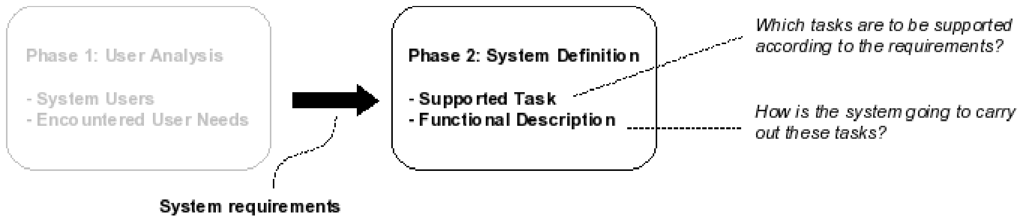


Fig 13: Phase 2, including 'supported task' and 'functional description'

It was found that the use of so called system states would result in a system that complies with the requirements. System states, drive-task support increasing with every next state, offer a flexible and adaptable system, which only support the driver if he wants to, or if necessary for traffic safety.

Next, the 'functional description' determined how the supported task was to be carried out. A first step towards a solution was the making of an ADAS roadmap. The roadmap indicated the expected availability of systems like ACC, FCW, ISA and LDW/LKS/LCA in the 2020 future.

These systems were analysed, determining their task support, functions and components. Their functions were put in a table, from which conclusions were drawn. These conclusions lead to the selection of components, which together formed the final ADAS system concept. The use of a forward looking camera, two radar systems and a communication device offers the user longitudinal control through ACC, FCW and ISA. Lateral control is provided by means of LDW, LCA and LKS.

Apart from the ADAS related components the system also uses a CPU, an interface for vehicle systems, an interface for vehicle actuators and a workload manager. The workload manager has been described more thoroughly because of the influence it has on the user interface.

The estimated power usage and physical properties of all these components are sufficiently low and small to justify the rather 'luxurious' collection of ADAS systems for a sustainable vehicle.

This chapter concludes phase 1 and phase 2 of the design approach. The result is a system concept, which consists of a set of specified components and their functionality. A user interface for this concept will be developed in phase 3, which is covered by the next chapter.

4. Interface Concept

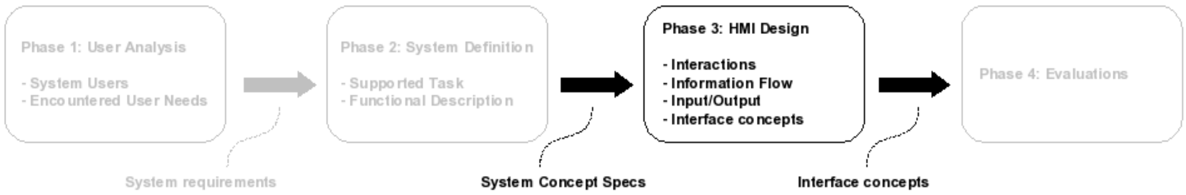


Fig 14: Phase 3 of the design process covers interactions, information flows, input/output and final concept design

The system concept specifications provide the starting point for the development of the interface concept. The goal of the interface design is to find a way to let the driver operate the system in a safe and effective way. The interaction between the driver and the vehicle will play a central role during the development of the interface.

Interactions between the user and the system (driver and vehicle) involve the input, processing and output of information flows. In order to design a safe and effective interface, all interaction aspects need to be investigated.

The first step is to further specify interactions within ADAS, using interaction diagrams. These diagrams will then be used to determine the information flows. In order to let the driver acquire and receive the information, input and output modalities also need to be investigated.

- *Paragraph 4.1 Define Interactions*
  - *Paragraph 4.2 Derive information flows*
  - *Paragraph 4.3 Derive input and output modalities*
- *Paragraph 4.4 Interface Concept design*

Combining the results of these investigations will result in a so called framework. The framework defines the underlying structure of the interface, for which external concepts can be designed. For this design, the HMI-specific requirements mentioned in Chapter 3 will be taken into account.

4.1 Interactions

As said in the introduction, interaction between the driver and the vehicle consists of the input, processing and output of information flows. Interactions are needed to perform the main driving task. The 'cruising' task for example involves observing preceding traffic, estimating following distance and speed, and applying the brake or throttle accordingly.

To further discuss ADAS related interactions, the interaction diagram shown below will be used. Each step of the interaction either requires or provides information. In normal circumstances, the driver will acquire information (observe, input), process it, and react accordingly (output).

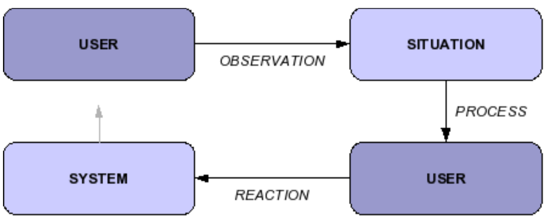


Fig 15: The extended system interaction diagram

Tasks & Interactions

After the definition of the interaction diagram, the next logical step would be to define the information flows of the interaction. However, the system states that are used in this concept cause some problems with that approach.

The effect of system state transitions on interactions is significant. Appendix 6 describes interaction diagrams for the three system states, in addition to the diagram presented above. Each state appears to require and provide different amounts of information, depending on *who's performing the task*; the driver or the system.

This effect is summarised in the table below. The table lists the available task functionality of the system concept, as presented in the previous chapter[43]. The four far right columns present a task allocation, based on system states. In brief, the table describes who's supposed to carry out a task in which state. This may be "User", "Both" or "ADAS". A combination of "User" and "ADAS" means that the user is backing up the task of ADAS.

Longitudinal Functions		***Task Allocation***			
Task	*Sub Tasks*	*Off*	*Inform*	*Assist*	*Control*
Vehicle & Obstacle detection	Scan Road	User	Both	Both	ADAS, User
Vehicle Tracking	Detect vehicle position Detect vehicle speed Detect vehicle distance Control Adjustments Warn HMI	User User User User	Both Both Both User ADAS	Both Both Both Both ADAS	ADAS, User ADAS, User ADAS, User ADAS, User ADAS
Obstacle Avoidance	Detect obstacle position Warn HMI Control Adjustments	User User User	Both ADAS User	Both ADAS Both	ADAS, User ADAS ADAS, User
Speed Limit Detection	Detect speed limit Control Adjustments Warn HMI	User User	Both User ADAS	Both Both ADAS	ADAS, User ADAS, User ADAS
Lateral Functions		***Task Allocation***			
Lane Tracking	Scan Road	User	Both	Both	ADAS, User
Lane keeping/Warning	Detect markings Detect deviations Determine corrections Control Adjustments Warn HMI	User User User User	Both Both Both User ADAS	Both Both Both Both ADAS	ADAS, User ADAS, User ADAS, User ADAS, User ADAS
Rear Vehicle Detection	Scan read road Detect vehicle position Detect vehicle speed Control Adjustments Warn HMI	User User User User	Both Both Both User ADAS	Both Both Both Both ADAS	ADAS, User ADAS, User ADAS, User ADAS, User ADAS

Table 16: The task allocation table

With ADAS inactive, the interactions between the driver and system are comparable to current vehicle interactions, as no task allocation has changed. More interesting are the informing and assistant modes, in which cooperation between the system and driver is needed.

The conclusion drawn from this table is that different amounts of information are needed for different system states. The table can also be used to determine which information should be presented, which will be done in the next paragraph.

43 See "System Functionality" in chapter 3

4.2 Information Flow

As concluded in the previous paragraph, the presentation of information changes as system states change. This paragraph will determine which information will be presented during a particular state. The task allocation table from the previous paragraph is used, resulting in the following overview.

Longitudinal Functions		***Presented Information***		
Task	*Sub Tasks*	*Inform*	*Assist*	*Control*
Vehicle & Obstacle detection	Scan Road	ADAS is active	ADAS is active	ADAS is active
Vehicle Tracking	Detect vehicle position Detect vehicle speed Detect vehicle distance Control Adjustments Warn HMI	Vehicle position and distance during unsafe situations	Vehicle position and distance during unsafe situations ADAS reaction	Vehicle position and distance during unsafe situations ADAS reaction
Obstacle Avoidance	Detect obstacle position Warn HMI Control Adjustments	Obstacle position and distance during unsafe situations	Obstacle position and distance during unsafe situations ADAS reaction	Obstacle position and distance during unsafe situations ADAS reaction
Speed Limit Detection	Detect speed limit Control Adjustments Warn HMI	Speed limit if exceeding	Speed limit if exceeding ADAS reaction	Keep speed below the speed limit
Lateral Functions		***Presented Information***		
Lane Tracking	Scan Road	ADAS is active	ADAS is active	ADAS is active
Lane keeping/Warning	Detect markings Detect deviations Determine corrections Control Adjustments Warn HMI	Warnings in case of lane departure	Warnings in case of lane departure ADAS reaction	ADAS is active Show anticipation
Rear Vehicle Detection	Scan read road Detect vehicle position Detect vehicle speed Control Adjustments Warn HMI	Warnings in case of unsafe lane changing	Warnings in case of unsafe lane changing ADAS reaction	Automatically change lanes

Table 17: Information divided by system states

The defined information flows can now be added to the interaction diagrams, as shown in Appendix 6. With these interaction diagrams, the interaction between the driver and the system concept has been described. Important findings are the following.

1. Different system states cause a changing need of both the amount and type of information. The information table shows how the information is to be distributed over the different system states.
2. The driver needs to be aware of the current system state, to prevent overestimation or underestimation of system functionalities. Therefore, the information table states that system activity should continually be indicated.
3. The driver needs to be able to influence the interactions, by altering system parameters.

The input channel is used by the driver to control the vehicle. This may either be directly, for example by pushing the brake, or indirectly, by telling the ADAS system to keep driving in the lane or to maintain a certain following distance. Furthermore, the interface should allow the driver to change settings of the ADAS system. For convenience, the input channel has been divided into two parts, namely the “Direct Controls” and the “Indirect Controls”. The table below presents a list of all controls and settings, and the parameters they affect.

Input		Parameter(s)
Direct Controls	Steering	Heading
	Throttle	Speed
	Brake	Speed
	Gear	Transfer ratio
Indirect Controls	System State Change	State 0/1/2/3
	Vehicle detection	On/Off
	Obstacle detection	On/Off
	Lane detection	On/Off
	Rear vehicle detection	On/Off
	Speed Limit detection	On/Off
	Lane keeping	Sensitivity, Tolerance
	Car tracking	Distance, Speed

Table 18: The list of input options

It's shown that the driver has the possibility to enable or disable several functions of the ADAS system, such as lane detection and obstacle detection. If the traffic situation is not suitable for the use of these systems, the driver or system may disable them.

The sensitivity and tolerance settings, as well as the following distance and speed are advanced settings. To comply to the adaptability system requirement, the interface should offer the user multiple layers of settings. More advanced settings like these should only appear if the (advanced) user asks for them.

Car tracking settings

The 'Distance' parameter sets the following distance, which is already common for current ACC systems. The range of this setting should be adaptable by the user, but should also be within safety limits. The parameter may be set in seconds (of following time) or meters (of following distance). The desired cruising speed should also be adjustable by the user. This speed can be checked with local speed limits, available through the ISA system.

Lane keeping settings

For lateral systems, the driver should be able to set the sensitivity and tolerance of the system. These parameters define how much the driver may deviate from the lane before a warning or intervention takes place, and how close a vehicle may approach from behind in case of lane changing.

4.3 Input/Output

This paragraph describes which input and output methods (or *modalities)* will be used in the interface concept. A lot of input and output modalities are available, including endless combinations between them.

Modality selection is influences by several factors.

- First, physical restrictions of the automotive interior apply. The modalities have to fit in to the Car of the Future cockpit.
- Second, the information that is sent through the modality limits the choice. For example, a simple LED can very well be used for on/off indication, but is less useful for the presentation of speed.
- Furthermore, sustainability should be considered. Fancy and futuristic modalities such as a touchscreen may be less favourable because of costs and/or power drain.

A problem with modality selection for automotive use is the fact that several input and output channels of the driver are already occupied by other tasks. For example, the driver spends most of his visual attention on the road, the traffic and the dashboard. It's therefore important for the interface to use available modalities. However, changing modalities all the time, or using several modalities for the same task would interfere with interface design principles, such as the principle of *coherence*[44].

To assist the selection of modalities, the so called *modality theory* was developed[45]. This theory tries to solve the 'information-mapping problem':

Given any particular set of information which needs to be exchanged between user and system during task performance in context, identify the input/output modalities which constitute an optimal solution to the representation and exchange of that information.

This problem is exactly the problem to be solved for this interface design. However, the modality theory does not yet offer a usable approach to the problem. A proposed approach includes the following steps.

1. Identification of information and tasks
2. Selective task analysis
3. Information representation
4. Information mapping
5. Trade-offs

The first three steps have already been covered in paragraphs 4.1 and 4.2. They generally concern the identification of tasks and their information flows. The fourth and fifth steps involve the selection and evaluation of modalities, based on a large matrix of combinations and their properties. The matrix can assist in answering generic questions like:

Available modalities are [good/not good] for a certain task/function

At this moment, such a matrix does not exist. The modality theory literature therefore recommends the use of empirical research to select modalities[46]. Relevant literature has been collected and summarised. The findings are as follows.

In current vehicles the driver receives most of the drive-task related information through the visual channel. Examples of drive-task related information are the observation of external traffic situations, or the monitoring of vehicle instruments. According to Wickens' Multiple Resource Theory[47], it would therefore be advisable to use other modalities for additional applications, such as navigational aids or ADAS systems. The same reason prevents the visual channel from being used for important warnings or messages. If presented visually, such information should be emphasised by auditory signals.[48]

44 Shneiderman's principles of HMI design, see http://www-static.cc.gatech.edu/classes/cs6751_97_winter/Topics/design-princ/
45 N.O. Bernsen, 1994
46 N.O. Bernsen, 1994
47 See Chapter 2, paragraph 1
48 M. Panou et al, 2005

For output, the most obvious choice would be an auditory modality, such as speech or tones. Auditory information has several specific properties in favour of in-vehicle use[49]. Firstly, auditory information is *omnidirectional*, so the information will reach the user regardless of his point of attention. Secondly, auditory information does not require visual or limb activity of the user. And finally, this modality has a high saliency, which means that the chance of the driver receiving and understanding the information is very high.

A drawback of the speech output modality is that the information lacks freedom of perceptual inspection. The driver can not decide when or how long to listen to the message. A common solution for this problem is the use of a repeat-button, which may also function as an interruption button. Also, the speech system may be linked to an awareness system (such as the workload manager) to produce output only when preferred by the driver.

In addition to the visual and auditory modalities, the haptic modality maybe used for input and output of information. For input, this modality has been used for years in the form of buttons, dials and switches. For output, this modality is relatively new. Examples of haptic output devices are force feedback steering wheels, vibrating seatbelts and vibrating seats. According to research[50], haptic signals may be used as supporting signals for visual or auditory warnings, or should be used for non-vital warnings.

Current automotive interior designs mainly use mechanical input modalities, such as knobs and switches. Besides these common input modalities the interface may also use auditory input methods. As the quality of speech recognition software increases, this method provides a good alternative to common input methods. The advantage of speech input is that the driver can keep his hands on the steering wheel.

Literature does not prescribe a particular modality to be the best choice for a certain situation. Survey results sometimes even contradict each other, but some conclusions are generally valid, as listed above. In conclusion, it's found that the visual channel is used for the main driving task. Therefore it is not available for high-priority warnings and information. Auditory signals and possible haptic signals maybe used to emphasise warnings and messages. For input, haptic devices are common. Speech input is a relatively new and probably safe auditory input method.

After this overview of interface modalities, it is up to the concept design to select particular devices. During the evaluation of these concepts, the literature results as described above can be used. To be able to compare the concepts with respect to input and output modalities, the following table has to be filled in for every concept.

INPUT/OUTPUT MODALITY SELECTION		***Visual***	***Auditory***	***Haptic***
Input	Direct			
	Indirect			
Output	Vehicle & Obstacle detection			
	Vehicle Tracking			
	Obstacle Avoidance			
	Speed Limit Detection			
	Lane Tracking			
	Lane keeping/Warning			
	Rear Vehicle Detection			

Table 19: Concept modality selection table

The table shows the required input and output fields, as defined in the preceding paragraphs. The three far right columns will be filled in with concept solutions. In case of multimodal solutions, a prioritisation will be indicated.

49 N. O. Bernsen, 2001
50 M. Panou et al, 2005

4.4 Interface Concepts

The preceding paragraphs of this chapter defined which information flows and interactions should be supported by the interface. To design interface concepts, the brainstorm method is used to collect ideas. These ideas can be combined to form complete concepts.

Boundary conditions

although the brainstorm should be 'open-minded', a few boundary conditions are appropriate. These boundary conditions have already been mentioned, in the form of HMI specific *system requirements*.

Requirement	***Requirement specification***	***Implementation***
Provide Safety	The system should enhance the safety of the vehicle, within limits of the project	The longitudinal and lateral support functions
	The system should not change the behaviour of the vehicle significantly, unless necessary	The use of system states
	The system should cooperate with non-assisted vehicles	The system-concept is autonomous, operating independently from infrastructure
	The system should support communications between users and vehicles	The system uses a communication device for speed limit detection
Provide Control	The system should let the user control ADAS influence	**HMI**
	The system should be adaptable by the user	**HMI**
Support Usability	The system should intelligently adapt to the driver's character, within safety limits	**System intelligence, HMI and workload manager**
	The system should support drivers of all ages, within legal limits	**HMI**
	The system should support information and entertainment systems	**HMI/Workload manager**
	The system should support sustainability	The system uses several multifunctional components

Table 20: System requirements

Besides the HMI specific requirements, the general requirements for example regarding sustainability should not be forgotten. The use of these requirements will make sure the interface concepts will comply to the project demands as well as research results, while also offering enough freedom to come up with new ideas.

Results

The collection of ideas resulted in four different concepts. These concepts mainly differ in their 'fanciness', ranging from a 'classic' concept to a very 'futuristic' concept. By presenting such a wide range of concepts, the Nexus project can select certain concepts that are expected to be successful within the project.

The four concepts will be presented by describing their characteristic properties. As this is only the first round of concept design, the level of detail will be low. The rough outline and heading of a concept should be enough for the Nexus project group to make a selection of.

The next four paragraphs will discuss the concepts more in-depth.

Concept 1 – Classic

The theme for this concept is "Classic". To keep the interface familiar and acceptable, conventional indicators and other interface components have been used. The main part of the interface is located on the centre front instrument panel. The usual dials (oil, fuel, etc.) are accompanied by an *integrated safety indicator* and an *enhanced speedometer*,which will be explained later.

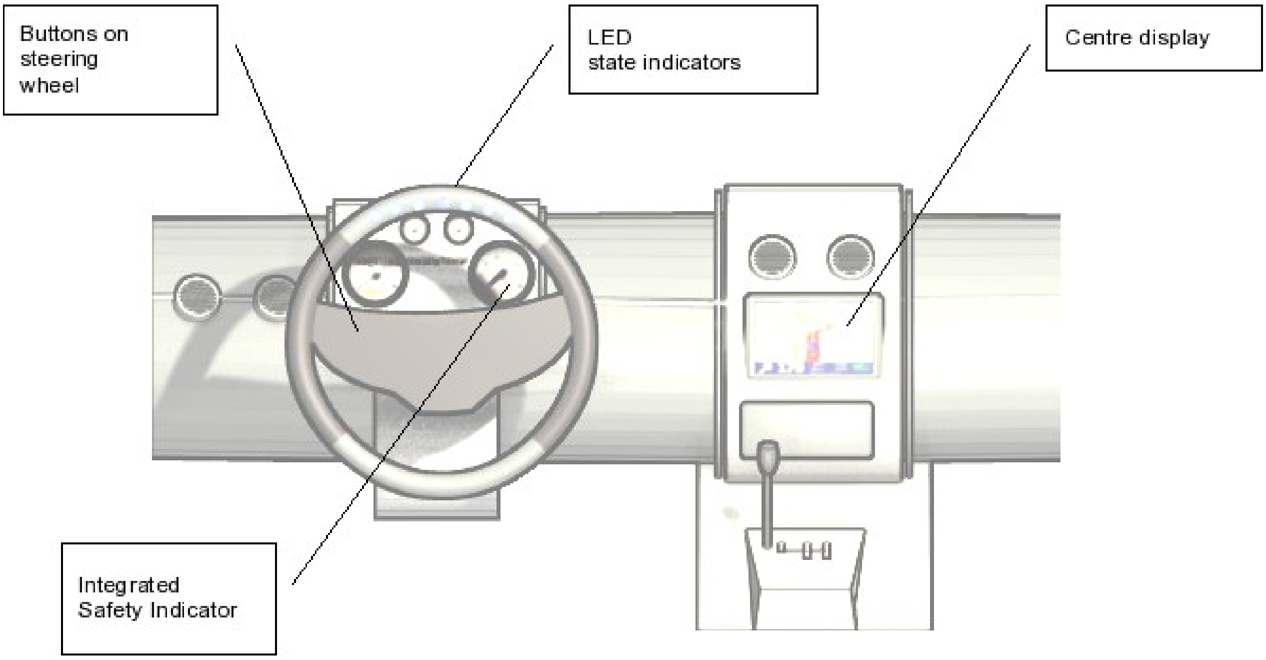


Fig 15: Overview of concept 1

System state is indicated by LEDs on the steering wheel and gear lever. When driving assisted or supported, the LEDs will indicate system activity by lighting up (constantly when in c*ontrolling state*, on activation when in *assisting state*). Changes in states are presented visually through LEDs and accompanied by auditory signals.

Input

The main input device for this concept is the steering wheel. The steering wheel offers a set of buttons to control menus on the centre console. Using this menu the user can alter advanced settings like following distance, sensor control and other preferences. Feedback of buttons is both visual (through actions on screen) and auditory (a sound signal when a button is pressed). It can be compared to steering wheels with integrated radio and cruise control buttons.

Enhanced Speedometer

The speedometer of this concept is enhanced using sensor data from the ADAS system. This way, the speedometer not only shows current local speed, but also the local speed limit, as well as advisory speeds based on traffic assessments.

Integrated Safety Indicator

The integrated safety indicator is a combination of a visual dial, similar to existing speedometers, and auditory feedback. The dial gives a rough first indication of danger, based on ADAS sensor data. The driver is given the opportunity to notice the danger indication and react on it. If no reaction is given, the indicator will use auditory feedback to indicate the danger and assist in returning to a safe situation.

The scale of the safety indicator ranges from safe to unsafe, with additional warning indicators in the unsafe area. In order to assess the safety of the traffic situation, sensor data are used. A statistical formula then calculates the real-time 'risk factor', based on the so called *time to collision (TTC)*[51].

TTC indicates the time to collision, if nothing changes in the current situation. So, with two vehicles following each other, a TTC will only exist (positively) if the speed of the following car is higher than that of the leading car. TTC can be calculated using the following formula[52].

$$\mathrm{TTC}_i = \frac{[X_{(i-1)}(t) - X_i(t) - l_i]}{[V_i(t) - V_{(i-1)}(t)]}$$

X is the location of a vehicle (at t)

V is the speed of a vehicle (at t)

l is the length of a vehicle

i represents the vehicle for which the TTC is being calculated, i-1 is the lead vehicle

The required parameters, such as the locations of vehicles relatively to each other can be derived from longitudinal sensor input. For longitudinal situations such as cruising on a busy highway this method works fine. However, problems arise when looking at lateral situations.

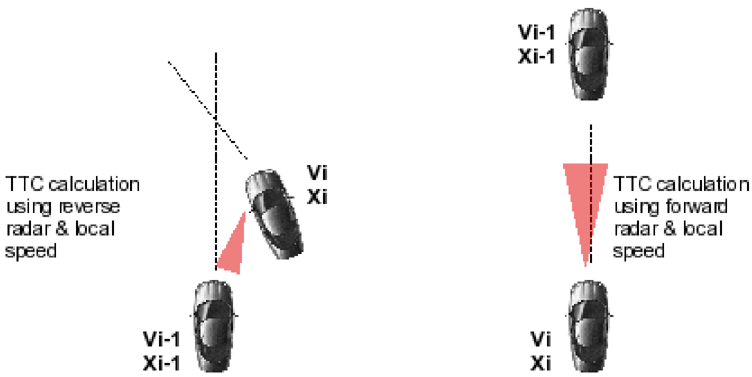


Fig 16: Real time TTC calculation in longitudinal and lateral situations

In lateral situations, TTC still applies, as shown in the left figure. A more predictive calculation is needed, using the values from rear radar sensors. The speed of the approaching vehicle (V_{i-1}) is important, as it highly influences the TTC calculation in such a situation. Also, the indicator shouldn't indicate danger every time a vehicle passes by, so a connection to the steering wheel may be useful, making sure only actual lateral danger is indicated.

System Integration

A drawback of this concept is the fact that it doesn't provide specific integration possibilities for information and entertainment systems. The lack of integration may be a drawback, but it does comply to the 'classic' and 'minimalistic' character of the concept. In case of a sustainable car, which doesn't need fancy multimedia, this concept may still be an attractive option.

51 K. Vogel, 2002
52 K. Vogel, 2002

Summarised, concept 1 offers a classic approach, with proven and existing technology. It fits the sustainable needs of the project, and offers additional safety to the driver. However, since the interface are designed for 2020, it may not be the most attractive solutions. Furthermore, the use of fixed dials and LEDs doesn't support system modularity or flexibility.

The input and output characteristics of this concept have been listed in the following table. The modality selection prioritisation is indicated by numbers. A '1' indicates highest priority.

INPUT/OUTPUT MODALITY SELECTION		***Visual***	***Auditory***	***Haptic***
Input	Direct			Steering, Brake, Throttle, Gear
	Indirect	2. Display on centre console	3. Auditory feedback	1. Buttons on steering wheel
Output	Vehicle & Obstacle detection	1. Integrated safety ind.	2. Auditory advice	
	Vehicle Tracking	1. LED indicators, 1. Integrated safety ind.	2. Auditory advice	
	Obstacle Avoidance	1. Integrated safety ind.	2. Auditory advice	
	Speed Limit Detection	1. Enhanced speedometer	2. Auditory advice	
	Lane Tracking	1. LED indicators	2. Auditory advice	
	Lane keeping/Warning	1. Integrated safety ind.	2. Auditory advice	
	Rear Vehicle Detection	1. Integrated safety ind.	2. Auditory advice	

Concept 2 – Adaptive Interface

The focus of this concept is on adaptability. The interface shows information depending on the system state, always providing both sufficient and efficient information. Adaptability can be achieved using software or hardware.

Input

Input for this concept is given through voice commands. Feedback on voice commands is given by auditory and visual cues. The steering wheel contains backup buttons for interface control, but voice commands should be the main source of input.

Adaptive software

Following the current trend of increasing use of displays instead of conventional vehicle instruments, the output of the software version is given through a digital display. On the display the usual dials and indicator can be shown, along with ADAS output. With system states changing to more supportive modes, the display will show more ADAS output, and minimise other systems.

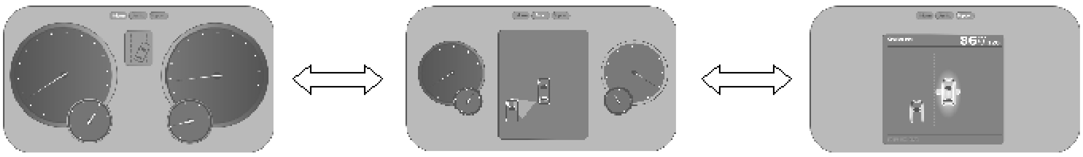


Fig 16: The software adaptive concept

Adaptive hardware

Using hardware, the dashboard can be altered according to system use. Dials and indicators can slide or rotate, in order to be visible or not. This way the user can get more 'in touch' with the system, and may better understand what's happening.

Grouping Information

The adaptive character of this concept introduces a possible problem with recognition and expectancy. Users may not always receive information from the same location. For example, when driving in the *informing state*, the vehicle speed is displayed large and in the centre-left part of the screen. After switching to a higher state of support, the speed maybe displayed smaller and in a different location.

Therefore it's necessary to define groups of information, as also recommended in several interface guidelines[53].

- Conventional vehicle dynamics; including speed, engine revolutions, fuel status.
- System failure indicators: warning lights and sounds for system failure, either vehicle or ADAS
- ADAS output: the visual display offers opportunities for ADAS output, as described below. In combination with buttons or voice control it may also be used as part of the input system for ADAS.
- Secondary system output: the display may also be used for secondary assistant applications like parking assistance and night-vision systems. The instrument cluster is not considered a suitable location for multimedia output.

Fig 17: The hardware adaptive concept

53 See Appendix 3

The hardware version should support grouping by placing information output devices on separate interior components. The software version can simply use a digital display to support this.

Output

Both concepts use a visual display to show which system state is active, and which ADAS systems are running. The following drawing shows the basic workings of such a display.

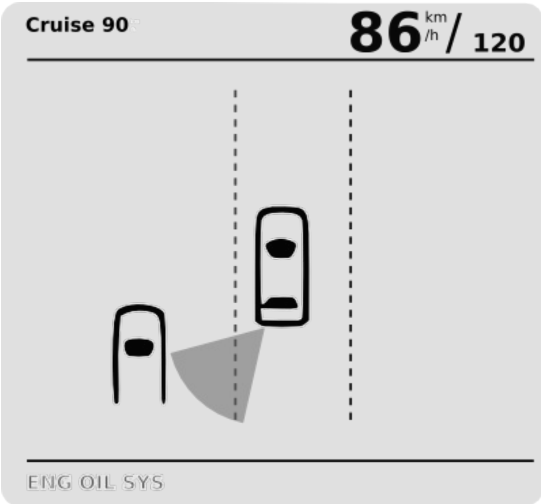


Fig 18: Concept ADAS display

The display uses a top-down perspective to indicate current vehicle and traffic conditions. Road markings can be used to show whether the lane keeping or lane departure (i.e. the lateral control and monitoring) functions are operating. If a system is active, for example the lane change assistance system as shown in the drawing, this can be indicated by highlighting the sensor area. Furthermore, a display like this offers integration possibilities with navigation and communication equipment.

INPUT/OUTPUT MODALITY SELECTION		***Visual***	***Auditory***	***Haptic***
Input	Direct			1. Steering, Brake, Throttle, Gear
	Indirect		1. Speech	2. Buttons on steering wheel
Output	Vehicle & Obstacle detection	1. ADAS display	2. Auditory support & advice	
	Vehicle Tracking	1. ADAS display	2. Auditory support & advice	
	Obstacle Avoidance	1. ADAS display	2. Auditory support & advice	
	Speed Limit Detection	1. ADAS display	2. Auditory support & advice	
	Lane Tracking	1. ADAS display	2. Auditory support & advice	
	Lane keeping/Warning	1. ADAS display	2. Auditory support & advice	
	Rear Vehicle Detection	1. ADAS display	2. Auditory support & advice	

Concept 3 – Futuristic

This concept uses relatively new and unproven technology[54] to provide the user with information. The main information output is shown on the windscreen, using an augmented reality display. On this display, the information is shown within the line of sight of the driver.

Input

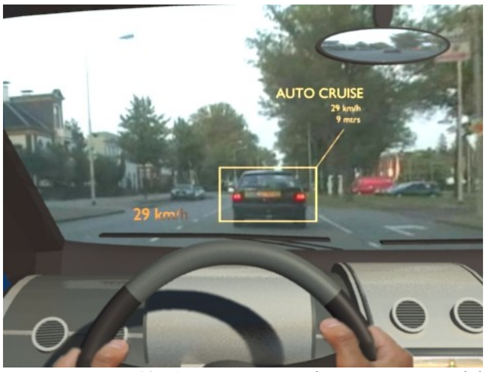


Fig 19: A HUD presented in a concept model

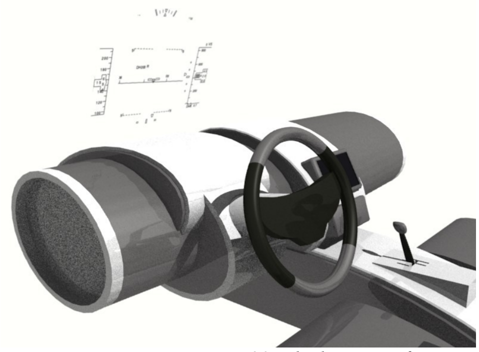


Fig 20: The location of a HUD

System input is given by voice commands only. A centre console touch-screen may be used as backup. With voice commands the user can control system parameters and preferences. Feedback is given through digitized speech output.

Output

Besides the speech output, most ADAS output is presented on the windshield display. The information changes according to system states. When driving manually, traditional information is shown, when driving in the *controlling state*, ADAS information is shown. The windshield display can be used to show path predictions, car tracking and obstacle highlighting. It also offers a platform for other car systems like navigational instruments.

INPUT/OUTPUT MODALITY SELECTION		***Visual***	***Auditory***	***Haptic***
Input	Direct			1. Steering, Brake, Throttle, Gear
	Indirect		1. Speech	
Output	Vehicle & Obstacle detection	1. On the HUD	2. Auditory support	
	Vehicle Tracking	1. On the HUD	2. Auditory support	
	Obstacle Avoidance	1. On the HUD	2. Auditory support	
	Speed Limit Detection	1. On the HUD	2. Auditory support	
	Lane Tracking	1. On the HUD	2. Auditory support	
	Lane keeping/Warning	1. On the HUD	2. Auditory support	
	Rear Vehicle Detection	1. On the HUD	2. Auditory support	

54 See Appendix 3.4

Concept 4 – Interactive Driver Assistant

The driver assistant is a physical or virtual appearance in the car, providing the driver with tips and advice on driving safety. Ideas for this concept include actual robots, computerised voices and virtual road buddies.

A physical form of driver assistant can also express certain traffic conditions or vehicle status. For example, a scanning movement of some kind can indicate system alertness.

With this concept focus is on interactions between the driver and the system, as well as with system intelligence. Intelligence should prevent the assistant from assisting too much, or it's unwanted.

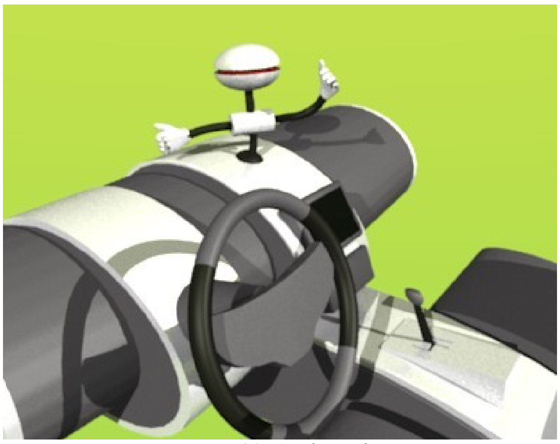


Fig 21: A robotic driver assistant concept

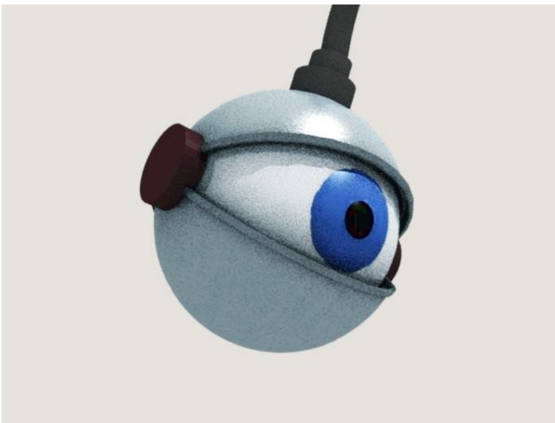


Fig 22: Another driver assistant concept

Input

The input method for this concept is voice control. By being able to communicate naturally with the car, a certain amount of trust and comfort can be created. The assistant will reply with voice answers. To control the system states, a physical robot could be aimed at a traffic situation. For example, aiming the face on the road would put the car in the *controlling mode*, aiming the face on the dashboard would put the car in assisting mode.

Output

System output is given through voice commands, visual cues and expressions of the assistant. These output channels may also be used by other car systems like information and navigational applications. The assistant should use expressions or movements to indicate alertness or inattention. The user should be able to trust the assistant to watch out if he wants him to do so.

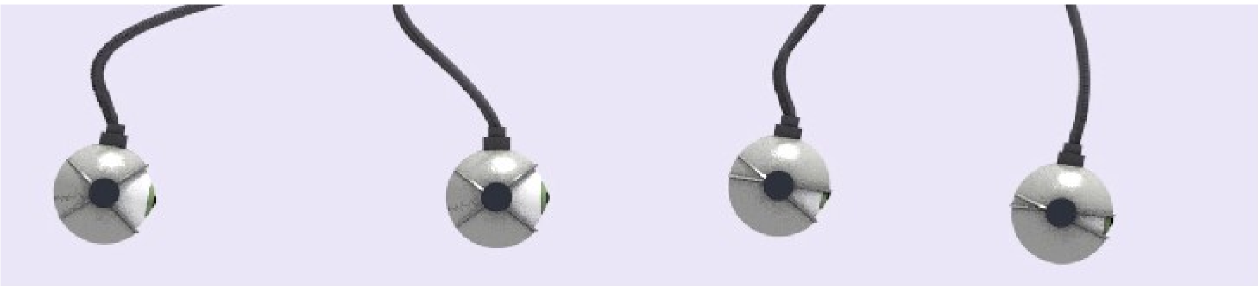


Fig 23: Expressions of a driver assistant concept

System Integration

The assistant concept is also able to present information and entertainment to the driver. Not only is the assistant aware of the traffic safety situation, he should also know when to play music, and which music to play. A personal bond with the assistant may also increase trust between him and the driver.

INPUT/OUTPUT MODALITY SELECTION		***Visual***	***Auditory***	***Haptic***
Input	Direct			1. Steering, Brake, Throttle, Gear
	Indirect		1. Speech	2. Assistant Physics
Output	Vehicle & Obstacle detection	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Vehicle Tracking	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Obstacle Avoidance	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Speed Limit Detection	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Lane Tracking	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Lane keeping/Warning	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics
	Rear Vehicle Detection	1. Assistant Expressions	1. Assistant speech	2. Assistant Physics

4.5 Conclusions

This chapter describes the design of user interface for the global system concept. The following aspects have been dealt with.

1. System/user interactions
2. System information flows
3. Input/output modalities
4. Interface concept design

Interactions between the user and the system have been defined for every system state. Interactions differ for every system state. The information, divided into observation, processing and reaction parts, changes with every state transition.

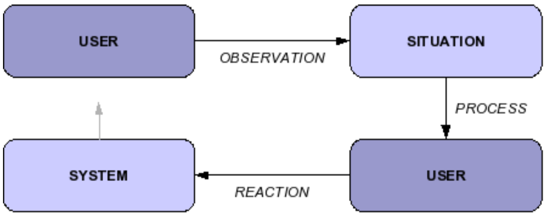


Fig 17: The basic interaction layout

It's found that most interesting interactions occur in the *assisting state*, and to some extent in the *controlling state*. In these states, the user and system have to cooperate to drive the vehicle. An inventory of information based on states was made, defining which information should be available at which moment. The system interactions and task allocation tables were used to support the selection.

The defined information flows have been divided into input and output. For this input and output, *modalities* were to be selected. Using the *modality theory* and a small literature overview, conclusions were drawn, and an input/output table for the interface concepts was set up. Together with the interaction diagrams and the information flows, this table provides an interface framework for which concepts can be designed.

Four ideas ranging from classic to futuristic, and with different levels of feasibility and sustainability have been described.

1. Classic – A conventional instrument cluster is used, on which a so called “integrated safety indicator” is located. The indicator will show whether a situation is safe or not, and what to do about it.
2. Adaptive – This concept uses hardware or software to adapt the interface according to a situation, thus always providing efficient yet sufficient information.
3. Futuristic – The windscreen of the vehicle is used to project imagery, showing vehicle and ADAS information within the line of sight of the user.
4. Road Assistant – A robotic or virtual road assistant will assist the driver with the driving task, navigation, and entertainment.

These concepts are to be evaluated in the next chapter, in order to make a first concept selection and further develop the remaining ideas.

5. Evaluations & Recommendations

The concepts as presented need to be further developed before they are able to be used in large-scale usability tests or even field tests. Therefore, this chapter will deal with an evaluation of both the global ADAS concept and the interface solutions, resulting in recommendations for further development.

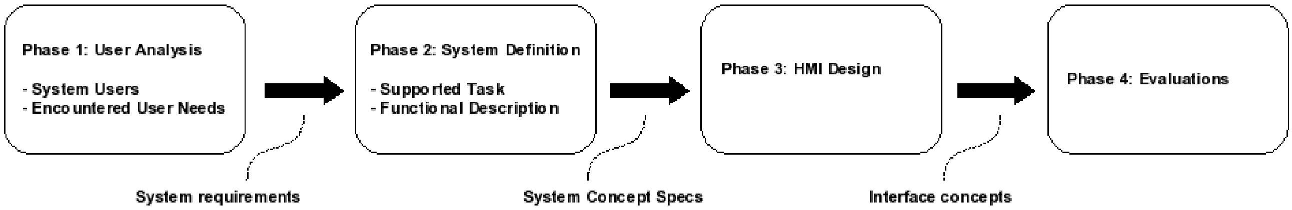


Fig 18: Evaluations, phase 4 of the design process

For the Systems Evaluation a review of development aspects is used. This method evaluates the global system concept. For the interface evaluation the Response Checklist part B is used. With this evaluation concepts will be evaluated individually.

5.1 System Evaluation

Development Aspects

The development aspects as described in chapter 2 are used. In chapter 2 three potential problem areas of ADAS systems have been discussed.

1. Introduction & Acceptance
2. Negative behavioural changes
3. Workload & driving task effects

So how does the presented ADAS concept handle these potential problems?

Introduction & Acceptance

The system uses technology that should be available in 2020, based on the ADAS roadmap. The roadmap reserves about 15 years of development time and for users to get acquainted with the new technology. However, some factors may affect the success of this roadmap. For example, if the government does not support the introduction of ADAS, it's impossible for further ADAS developments to succeed as law needs to be adapted to this new technology.

As said in literature, acceptance shouldn't be problematic as long as the system offers the user to remain in control if he/she prefers to do so. The system concept as presented offers this functionality by using different system states. Acceptance also depends on trust. Therefore ADAS systems should be tested thoroughly before market introduction. A negative first experience may cause the general public to reject ADAS.

Negative Behavioural Changes

It's hard to evaluate this aspect without conducting a long-term usability or field test. However, it can be said that both 'Individual Factors' and 'Learning Time' are covered by the systems intelligence. This intelligence causes the system to get to know the user, and adapt accordingly. This causes optimized interactions and consequently safer driving.

For this to succeed it is vital that the artificial intelligence as well as the human-machine interaction of the system is further investigated.

Workload & Driving Task Effects

The integration of a workload management system should prevent mental overload. A problem with such a solution is the lack of modularity of it. In the Car of the Future the user may add or remove parts and components, like PDAs, phones, etcetera. The workload manager should be designed to be adaptable, so that it adapts to every car configuration.

If successful, the system concept offers a lot of time space for secondary driving tasks, or even non-driving related tasks like work or leisure. The workload manager is capable of combining ADAS systems with these other applications.

Design Method

The design process that was used to develop the ADAS concept turned out to be positive. The RESPONSE Checklist part A is found suitable for global system development by pointing out important development aspects, as well as offering the possibility to fine-tune the list.

The following issues are worth mentioning.

– The result of the fine-tuning is that some important aspects have been left out because of time restrictions. These aspects need to be investigated in further research. The aspects include “Compliance to standards and traffic law” and “System Price”.

– The function analysis of ADAS systems to sub-function level resulted in a set of requirements for a potential new kind of integrated sensor. Further investigation of this subject may lead to the development of such a device, saving energy and space in future ADAS systems.

– While working on the interface framework it was found that the global system concept needed to be updated constantly. For future use of the ADAS checklist part A, a close integration between the global design and the HMI development is recommended.

5.2 Interface Evaluation

RESPONSE Checklist

The first method of evaluation for the interface will be the RESPONSE Checklist, Part B, as mentioned in chapter 2. Part B consists of a list of questions, with specific questions about HMI, system design, system use, etcetera. Each question affects a so called 'evaluation concept'. For example, a question about the use of the HMI may affect the evaluation concepts “Trust” and “Acceptance”.

The HMI chapter of the Checklist part B is used. A complete evaluation is presented in Appendix 8. The matrix below shows the total result of each evaluation aspect. Every aspect is awarded with 1 to 3 points, where 3 points indicate maximum positive effects on an evaluation concept.

Concept	***Predictability***	***Controllability***	***Traffic Safety***	***Responsibility***	***Misuse Potential***	***Driving Efficiency***	***Workload***	***Error Robustness***	***Trust***	***Perceptibility***	***Acceptance***
1. Classic	4/6	3/3	6/9	15/21	1/3	3/3	6/6	7/9	7/9	2/6	2/3
2. Adaptable interface	6/6	3/3	9/9	17/21	2/3	3/3	5/6	9/9	8/9	4/6	2/3
3. Futuristic	3/6	3/3	9/9	16/21	2/3	3/3	6/6	9/9	9/9	6/6	3/3
4. Road Assistant	5/6	3/3	8/9	15/21	3/3	2/3	5/6	9/9	9/9	5/6	3/3

Table 21: Results of the Checklist part B system evaluation

It should be noted that filling out the evaluation questions is not a pure scientific or objective task. The evaluation compares relatively feasible technology (concepts 1 and 2) to more futuristic technology (concepts 3 and 4). Also, questions often refer to detailed design aspects, such as menu design or use of speech messages. At this stage, design concepts haven't reached that level of specification yet.

Therefore, the numerical result of this evaluation (concept 3 scores highest) should not be interpreted as a victory for this concept. However, answering the questions does provide the designer with previously underestimated or forgotten design aspects. These aspects are listed below for each concept.

Concept 1

On the whole, concept 1 is evaluated as somewhat negative. The most interesting benefits of this concept are the use of familiar output methods which results in high acceptance and easy adaptation to new technology.

However, significant limitations to the concept have been found.

Firstly, negative behavioural changes may be caused by misinterpretation of the longitudinal safety indicator. Instead of merely indicating 'safe' or 'not safe', the interface should also support the driver (up to a certain level) by presenting messages that may be helpful.

Another problem with the interface is the use of steering-wheel buttons. There's a chance of accidentally pressing these buttons while driving, which may result in hazardous situations. To prevent this, button placement should prevent accidental pressing, either by not placing them on the steering-wheel, or by inactivating them when the steering-wheel is in use.

Finally, the amount of feedback of this interface is very minimal. The LED system that's used to indicate system activity should be improved to prevent misinterpretation. It should be made clear to the driver whether the system is actively driving, or asking for input.

Concept 2

No major concerns with this concept were found. The interface is expected to be accepted quite easily because of the familiar technology.

Possible problems are expected with driver attention. As the interface is located below the line of sight of the driver, it may be hard for a small display to get enough attention in case of emergency. Therefore it's necessary for the visual cues to be supported by auditory signals.

Concept 3

Concept 3 turns out to be quite positive. The use of a display within the line of sight of the driver may increase safety by preventing the driver from looking down too often. Information displayed on the HUD has a good chance of being noticed, and can be interpreted quickly.

A major drawback of this concept is the use of new technology. although HUDs appear in production cars more and more often it's still an unproven technology in the automotive industry. However, taking into account the future aspects of this design project this may not be a big issue.

Concept 4

As with concept 3, this concept may have problems with acceptance. It's unclear whether the robot or software assistant will cooperate safely and effectively with the driver. However, human-machine robotics and artificial intelligence is an active field of science.

European Statement of Principles

The second method to evaluate the interface concepts is to use the European Statement of Principles regarding automotive HMI design. Appendix 8 contains an overview with all the principles and their relation with the interface concept.

Although the principles check-up did not result in as much feedback as expected, the following issues were found interesting enough to be mentioned.

Principle 1.4 - "The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users"

Concept 1 may potentially cause negative behavioural changes because it doesn't always indicate what's going wrong exactly. This is a major drawback of the concept, and should be considered for re-design. The other concepts use explicit warnings and assistance to inform the user.

Principle 2.2 - "No part of the system should obstruct the driver's view of the road scene"

This guideline is relevant for several concepts. First, concept 3 uses a windshield display. This solution is not yet allowed in certain countries, partly because of this guideline. Though HUDs are becoming more common, research should further investigate the benefits of these displays.

Furthermore, concept 4 may have a problem, as it uses a physical appearance to assist the user. This 'robot' shouldn't obstruct the field of vision, but at the same time must be noticed in case of emergencies.

Principle 2.5 - "Visual displays should be designed and installed to avoid glare and reflections"

Only concept 3 may have major problems with glare and reflections. Further development of head-up displays and other transparent display technology may come with solutions.

Principle 4.3 - "System controls should be designed such that they can be operated without adverse impact on the primary driving controls"

Only concept 1 may have problems with this guideline, as it uses controls fitted on the steering wheel. Concepts 2 to 4 mainly use voice control.

5.3 Recommendations & Future Research

System Concept

The system concept presented in this research is used as a basis for further interface design, and should not be used as a final system design. However, as it has been designed with support of literature and research results, the concept describes a well-thought out and reasonable system.

Furthermore, the research was primarily safety oriented, possibly causing the comfort factors and attractive aspects to diminish. It's assumed however that by striving for safety the other factors will be dealt with as well.

On the whole, the system concept fulfils the requirements of both stakeholders and pre-defined evaluation methods. More detailed designing is necessary before actual implementation in to the Car of the Future. The evaluation of the system concept provides us with the following recommendations for future research.

- Further research on both general and traffic law is required
- System price factors are to be investigated
- The workload manager design needs to be extended
- The design of a new integrated sensor may be required/preferable for a sustainable Car of the Future

Interface Concepts

The four interface concepts have been evaluated as well. As it's the first generation of concepts, a lot of potential problems and improvements have been found thanks to evaluations. These results should be used to further develop the concepts, and finally make a smaller selection to further evaluate and improve.

For each concepts it's benefits and drawbacks are summarised below.

Concept	*Benefits*	*Drawbacks*
1. Classic	Familiar interface components Cheap interface components Low implementation costs	Unattractive, not futuristic Not adaptable/flexible Not modular or upgradable High maintenance costs No integration with other in-car systems
2. Adaptive	Futuristic, attractive Familiar interface components Cheap interface components Adaptable and flexible Integrates with other in-car systems Low maintenance costs	High implementation costs Possibly disorientating
3. Futuristic	Futuristic, attractive Adaptable and flexible Possibly safer Lower workload Integrates with other in-car systems	Expensive components Unproven technology High implementation/maintenance costs Practical restrictions
4. Road Assistant	Futuristic, attractive Trustworthy Adaptable and flexible Lower workload Integrates with other in-car systems	Expensive components Unproven technology High implementation/maintenance costs Practical restrictions

Table 22: Summary of benefits and drawbacks of interface concepts

Development Recommendations

Based on this research it would be advisable to further investigate possibilities of the “Adaptive Interface”, concept 2. Current research and technology support the use of adaptive interfaces, and car manufacturers are already increasing the use of digital displays in their vehicles.

The use of the digital version is advised, as it offers optimal integration opportunities with other in-car applications like navigation and multimedia systems. Also, it leaves quite a lot of design freedom with the interior designers, as long as space is reserved for a digital display, roughly the size of current instrument clusters.

However, taking in account the futuristic character of the project, it may be more interesting to further investigate the “Road Assistant” , concept 4. The use of a human-like assistant may be the key to gain trust among drivers, to let them rely on the system to support them.

Further research could look at human-robotics interactions (HRI) and robotic expressions. Current restrictions, such as traffic and general law and interface guidelines regarding distracting and obstructing components, should be kept in mind. The interface evaluation results can be used to do so.

5.4 Conclusions

The chapter covers the evaluation of both the global system concept and the four interface concepts.

Evaluation of the system concept is done using the development problems stated in chapter 2, being “Introduction & acceptance”, “Negative behavioural changes” and “Workload & driver task effects”. It turns out that the system concept has fitting solutions for these problems. However, as it is only a concept design, the further development of artificial intelligence and a workload management component are pointed out as future requirements.

The interfaces have been evaluated using the HMI section of the RESPONSE Checklist part B, as well as by evaluating design principles from the EsoP. Results of these evaluations indicate that the concepts need further development. Concept 2 turns out to be most feasible based on these results, while concept 4 is also recommended for further research, based on project preferences.

A summary of benefits and drawbacks of each concept has been made, along with recommendations for the further developing of both concepts 2 and 4.

Abbreviations

ABS	Anti Blocking System
ADAS	Advanced Driver Assistance System
ACC	Adaptive Cruise Control / Advanced Cruise Control
AID	Augmented Information Display
AIDE	Adaptive Interface Design
ADASE	Advanced Driver Assistance Europe
CC	Cruise Control
CPU	Central Processing Unit
ESP	Electronic Stability Program
HDD	Head-Down Display
HMI	Human Machine Interface
HUD	Head-Up Display
IVS	Intelligent Vehicle Systems
IVIS	Intelligent Vehicle Information Systems
ITS	Intelligent Traffic Systems
ISA	Intelligent Speed Adaptation / Intelligent Speed Assistance
LCA	Lane Change Assistant
LKS	Lane Keeping System
LDW	Lane Departure Warning
LDWa	Lane Departure Warning Assistant
SNE	Society for Nature and Environment
STD	State Transition Diagram
TuD	University of Delft
TuE	University of Eindhoven
UI	User Interface
UT	University of Twente

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Afterword

This assignment concludes the Bachelor part of my Industrial Design study. The field of science it covers, that of ADAS, ITS and automotive in general turned out to be an interesting and enormous one. So while working on this research the focus shifted from pure interface design to both system design and interface design. As a result, both designs are less in-depth than initially objected.

Despite the lack of in-depth design, the shifted focus did enforce me to use a more broader set of methods and techniques, including those of Systems Engineering, Ergonomics and general design courses. I'm quite pleased with the result, though sometimes it looks more like a collection of knowledge, conclusions and repetition of sources. In my opinion, the final concepts certainly contain new ideas, but need to be further developed before being implemented in the Car of the Future.

The cooperation with students and partners from the Car of the Future project was not entirely as expected, but interesting nevertheless. The different design approaches universities used sometimes caused communication problems, but never lead to a crisis. On the whole, the Nexus group and our meetings were often (but not always) inspiring and useful for my individual assignment. Therefore I'd like to thank Jacco, Niels, Gilbert, Martin, Jeroen and Gertjan.

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And last but not least I'd like to thank Gertjan and Marjan for pre-reading the report. Their comments were of great use for the final result[55].

55 Don't blame them for spelling errors on this page, as it was written afterwards