CHALMERS
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Visual interfaces for safety and enhanced driving experiences

An HMI concept for conveying technical failures in Advanced Driver Assistance Systems

Master of Science thesis in Product Development

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Division of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

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Cover:
The Left half of the image shows a car-following scenario while driving with Adaptive Cruise Controls with the distance between the vehicles depicted as dotted lines. The Right half of the image shows a screenshot from the final design concept.

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Abstract

Advanced Driver Assistance Systems have been in development for several years in the automotive industry and the technology is advancing year after year. These systems contribute to safety and comfort of the driver with the introduction of automation providing a better driving experience. Adaptive Cruise Control or ACC is one such system where the concept of automation has taken over parts of vehicle control according to driver's convenience. These systems are not fail-safe and with continuous improvements in the interfaces, it is possible to make them more adaptable to the end-user. The purpose of this master's thesis was to develop further knowledge on how a human-machine interface could be designed for notifying adaptive cruise control failures.

The objective of the work was to design, test and evaluate an interface that communicates to the driver of any technical failures that may occur in adaptive cruise controls. Several studies have been conducted to understand driver behaviour during the use of ACC but have seldom focussed on developing knowledge on designing an HMI for these systems.

An exploratory research methodology with a simulator-based iterative design process was used to state the underlying problems within the human machine system and for designing concepts. The early phase involved literature study on interaction between drivers and advanced driver assistance systems from the SHADES research project and relevant literatures on automation, psychology and interaction design to outline the underlying HMI issues. Several requirement guidelines were then mapped to the identified HMI issues which were used for generating HMI concepts. The final prototype was installed in a static desktop driving simulator at VTI for usability tests. An ACC braking malfunction was considered in three different scenarios for user evaluations.

Results indicated that continuous information regarding automated functions is a viable option for the drivers. It was also noted that drivers generally prefer warning information to be conveyed through auditory modalities when engaged in a driving task even when automation was involved. The results also suggested that presenting visual information related to primary driving tasks (longitudinal and lateral control of the vehicle) in the secondary display area is not advisable in critical failure conditions.

Keywords: Visual interface, automation failures, adaptive cruise control, HMI, simulator-based design

Preface

This thesis was performed at VTI (The Swedish National Road and Transport Research Institute). This work is a part of the SHADES (System Safety through the Combination of HMI and Dependable Systems) research project. Partners in SHADES are VTI, SP Technical Research Institute of Sweden, Chalmers University of Technology, AB Volvo and Volvo Car Corporation.

The work corresponds to 30 higher education credits and fulfils partial requirement for a master's degree in Product Development at Chalmers University of Technology, Gothenburg, Sweden.

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Furthermore, I owe many thanks to Bruno Augusto for his contribution to this work. Without his expertise in vehicle technology and simulation, it would have been impossible to setup the necessary simulation environment for usability tests. I would also like to extend my thanks to Irshad Pananilath and my brother Anil Das P.V., doctoral candidates from the Indian Institute of Science who managed to spare time during their tiring schedules and extended their immense help and support during the development of the interface application.

I would like to thank all the participants in my survey and simulator tests who have contributed to this project by willingly sharing their valuable time. I thank them for their valuable feedbacks during the course of the interviews.

I cannot express how grateful I am to my mother, father, sister and my brother for the prayers and sacrifices you have made on my behalf. Without you, I would not have sustained this far. Thank you again.

Last but not the least; I would like to thank everyone at VTI for their continuous support and contribution to the project.

To Mom and Dad

"Beauty and brains, pleasure and usability – They should go hand in hand."

-Don Norman

List of Abbreviations

ADAS	Advanced Driver Assistance Systems
ACC	Adaptive Cruise Control
HUD	Head-up display
HMI	Human Machine Interface/Interaction
HCI	Human-Computer Interaction
IVIS	In-vehicle information systems
OS	Operating System
rpm	Revolutions per minute
SA	Situation Awareness
SME	Small and Medium-sized Enterprises
SHADES	System Safety through the Combination of HMI and Dependable Systems
SBD	Simulator-Based Design
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UI	User Interface
VISES	Visual Interfaces for Safety and Enhanced driving Experiences
XAML	Extensible Application Mark-up Language

Structure

This report is divided into six chapters in total;

Chapter 1 is introduction which covers the background, purpose and scope of this work. The chapter gives a brief overview of the research subject and the need for carrying out this design task.

Chapter 2 is literature review where all the significant literatures connected with the results of this work are briefly described. This will cover all the relevant topics, which served as a principal foundation for understanding the technology i.e. adaptive cruise controls, the concept of automation in the human-machine system, concept of human perception and automotive interaction design. The theory will provide the reader with a better picture of how driving tasks and automation are connected and how it affects driver behaviour and performance.

Chapter 3 presents all the methodology used in the research phase, design phase and evaluation phases of the project and how these methodologies helped realize the design concept for usability tests. The methodologies will be described in the sequence these were used as the project progressed.

Chapter 4 includes the results from the usability evaluations of the design concept.

Chapter 5 is discussions of the methodologies and results.

Chapter 6 presents the conclusion for the project with recommendations for future work.

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1. Introduction

1.1 Background

Automation in cars has profoundly transformed the face of the automotive industry and is continuing to do so with the introduction of several Advanced Driver Assistance Systems. These systems provide adequate support to the drivers by reducing the number of driving functions to deal with in a modern driving environment. Adaptive Cruise Control is one such system which offers the driver with a more relaxed form of driving by partly taking care of lateral and longitudinal control of the vehicle. Meaning the driver has to actively monitor the status of the traffic while using this system, and resume manual control when needed.

With the introduction of automation in vehicles, the demand for human cognition increases whereas that of human actions is reduced (Anon n.d.). Studies have shown a decreased driver's workload while using these systems, but at the same time have also reported negative effects such as delays in driver responses (Strand et al. 2011) and negative behavioural adaptations (Hoedemaeker & Brookhuis 1998). It is appropriate to say that although ACC has its own potential benefits linked with automation, there is always a possibility for misuse or disuse of the system (Parasuraman & Riley 1997). Several driving simulator studies have also been conducted to learn safety effects of ACC. Nilsson (1995) studied driver behaviour in critical situations and indicated that there were more crashes when a stationary queue of vehicles was approached by the drivers' with cars fitted with ACC than without it. Another driving simulator study conducted by Stanton et al. (1997) indicated that drivers failed to reclaim manual control when the ACC failed to detect a vehicle in its path.

According to Larsson (2012) ADASs make driving a completely different activity where automation takes an active part in control. The importance of designing warning signals and allocating functions gradually rise due to the increase in allocation of driver tasks to driver support systems such as speed support and distance keeping as in adaptive cruise controls. These systems must be designed so as to prepare the driver to resume manual control of the vehicle when needed and not rely completely on the aspect of conditional automation. This eases the complexity of use for the driver and could make the system viable for all types of users.

All these studies indicate safety and acceptance are still a concern while using these systems and system errors need to be addressed if we are to design an appropriate HMI for an automated function.

1.1.1 System safety through the combination of HMI and dependable systems (SHADES)

SHADES is a research project funded by SAFER, the Vehicle and Traffic Safety Centre at Chalmers University of Technology. The project's objective is to combine the two fields of Human-Machine Interaction and Dependable systems to improve system safety in vehicles. It is evident that system errors are a concern for safety and for the same reason, SHADES research focusses on studying system errors linked with driving tasks (Strand 2012; Nilsson 2011). This thesis work is a part of SHADES and a large part of the background study and theoretical research conducted in this project has been from the existing SHADES literature.

Understanding driver behaviour on exposure to technical failures in Adaptive Cruise Controls was a prime focus of SHADES study. ACC system perception and interaction with ACC's, handling of technical failures by drivers, understanding the consequences of these failures and implications for diagnosing these failures were some of the themes in SHADES. Here, I will present an overview and a summary of findings of the SHADES study conducted by Strand, et al. during phase I of SHADES project.

Phase I of SHADES focussed on studying two aspects related to ACC usage;

1. Exploring end-user experience of using ACC in real traffic over time.
2. Automation failures in longitudinal control when using ACC.

First study was a focus group study with three interview sessions involving 5-7 persons in each. The discussions focussed on three themes, namely: usage of the systems, trust and functional limitations, and driving behaviour. Results indicated that different drivers had different mental models of the ACC system, and driving behaviour while using these systems changed over time. It was indicated in the findings that few users adapted strategies to cope with the system's functional limitations. One such strategy adopted by the users was to override the system and take manual control of speed when there was a delay in ACC acceleration while overtaking another vehicle. Mode errors were also a concern among the participants. An improvement to the current system by clearly indicating the current mode of operation was suggested.

Study 2 was a driving simulator experiment with a focus on automation failures in longitudinal control when using ACC. 48 participants were recruited who had no prior experience driving with ACC. However, practice scenarios were run to brief the functionality of the simulator and the ACC prior to running the driving scenarios. Four scenarios were included which were based on four main ways in which the ACC could malfunction.

1. Acceleration failure in which the simulator vehicle operated by the driver disregarded the set time interval and speed. Without any intervention from the driver collided with the lead vehicle.
2. Complete brake failure when the ACC failed to initiate any brake power when the lead vehicle braked resulting in a diminished time interval leading to collision.
3. Partial brake failure when the ACC initiated partial braking power when the lead vehicle braked thus resulting in a diminished time interval eventually resulting in collision.
4. Speeding failure scenario where the set speed was neglected but the time interval was respected. In this case if the lead vehicle accelerated to a higher speed, the ACC commanded acceleration by maintaining the time interval.

Results indicated a trade-off relationship between letting a failing ACC operational and keeping it turned on when failures are detected. Both had their drawbacks and benefits. When the drivers left the system operational, there was a confusion of what mode the system was operating in. However, the impact speeds were shorter in this case. On the other hand, when the drivers turned the system off, these led to lesser collisions but had higher impact speeds when collisions did occur. Study suggested that a best result could be achieved if the system stayed operational and also provided information to the drivers.

Another interesting input was that drivers preferred to use steering when automation failures affected braking or acceleration. Drivers handled the situation by steering away from the threat. A clear contributing factor to this preference is that the driver being separated from the longitudinal control of the vehicle, favour steering while driving with ACC (Strand et al. 2011). The author also indicates that if a failure is detected, either the driver could be informed to turn the system off or the system itself could initiate a technical response. This clearly suggests the importance of designing intervention strategies (request a driver response; initiate a technical response; combinations) to decrease the likelihood of severe consequences of failures in critical situations (see figure 1).

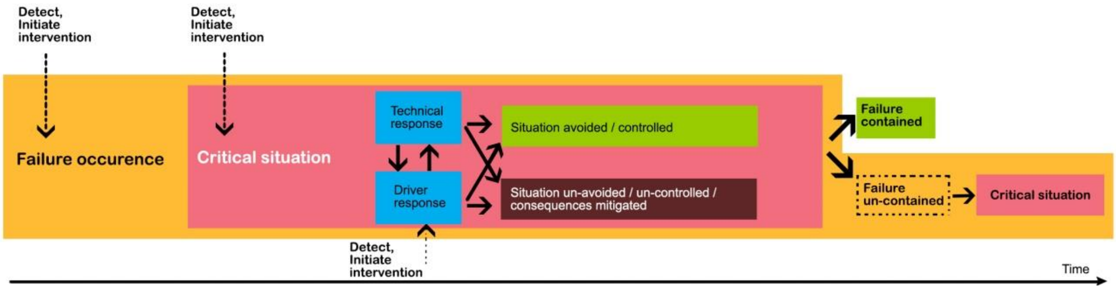

Figure 1: Overview of failures in relation to critical situations, driver-vehicle responses outcome. (Strand et al. 2011).

A suggestion for further research in the SHADES study was with regard to investigating the influence of driver's mental models towards use of ADAS and similar systems. An interesting subject would be to understand how the mental models could be enhanced, for instance, through alterations in user interfaces or through training to ensure favourable outcomes while using these systems.

Another suggestion was to investigate intervention strategies based on knowledge about human-machine-interaction with regard to ADAS. This was to aid safe-acts and to prevent as much as possible, unfavourable outcomes of automation failures.

1.1.2 User-centered design

According to Alm (2007), the interaction between the operator and the technical part of the joint system is highly valuable. To get a deeper insight into this, the concept of user-centred design has been developed within Human-Computer Interaction (HCI). The challenge here is to understand the way a human-machine system is used by observing and measuring the performance of users. It is the interaction that is important and the outcome of interactive processes (Alm 2007). In such cases, the term 'Usability Design' is much more informative than user-centered design.

Usability has been defined by the International Organization for Standardization in ISO 9241-11 (1998) (Usability Professionals' Association n.d.) as 'The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.'

However this definition is relevant but not sufficient in case of traffic environments since safety is a critical aspect of consideration. In the vehicular area a Simulator-Based Design approach is much more relevant. According to Gould, Boies, & Ukelson, 1997 (cited in Alm 2007), SBD is a way to achieve a usable system by:

- Having early and continuous focus on users
- Doing empirical measurements
- Doing iterative design and redesign
- Doing integrated design wherein all aspects of usability evolve together

1.2 Purpose/ Aim

The purpose of this thesis was to develop further knowledge on how an interface could be designed for notifying failures and modes of operation of an adaptive cruise control system in order to assist the drivers in making the right decisions during the course of failure. This is a research area which is still in its early stages of development with several questions regarding designing interfaces for automation yet to be answered. The thesis explored the possibilities of designing an in-vehicle interface for a driver under the influence of Adaptive Cruise Control.

The work was aimed at answering two sets of research questions:

- *How should the interface of an adaptive cruise control system be designed in order to support transition between different modes in the system?*

- *How can failures in the adaptive cruise control system be notified so that the drivers make the right decision under different driving scenarios?*

The goal was to generate a design concept with possible integration of multiple modalities (vision and hearing) in the ITERATE simulator at VTI (The Swedish National Road and Transport Research Institute). The concept was then evaluated in the simulator with potential participants.

1.2.1 Scope

The focus of this thesis was restricted to designing a visual interface that conveys technical failures in an Adaptive Cruise Control. Although other feedbacks such as audio warnings have been considered, no specific sound evaluation tools have been used to test credibility of these notifications apart from few user interviews and heuristic evaluations.

A low fidelity simulator was used for usability tests. These simulators provide very limited feedbacks to the driver in terms of kinaesthetic and vehicle dynamics. The choice to use a fixed-base simulator was on the criteria that this would be an initial setting for the task under investigation and would serve as a foundation for further iterations of the interface design in the future.

The number of scenarios in the simulator tests was restricted to three and involved only twelve drivers.

2. Literature review

2.1 Theories in Automation

Parasuraman & Riley (1997: p.231) define automation as 'the execution by a machine agent (usually a computer) of a function that was previously carried out by a human.' Automation of several physical functions in a system has helped humans save time and energy to a large extent. At the same time, automation of cognitive functions still remains rare (Parasuraman & Riley 1997). The need for providing the right feedback regarding the state of automation and addressing human performance issues while designing for automation has increased due to several accidents in the aviation and transportation sectors that have occurred in the past due to the selection of wrong guidance modes by the pilots and drivers. Whenever automation is involved in accidents, the interest lies in understanding how the operator used the system; whether they were over reliant, under reliant or used automation inappropriately.

Parasuraman & Riley (1997) discuss the factors influencing use, misuse, disuse and abuse of automation. *Use* of automation refers to varying personal attitudes towards a system. Factors such as mental workload, cognitive overhead, trust, confidence and risk influence use of automation. *Misuse* refers to relying inappropriately on automation and is affected by overreliance, decision biases and human monitoring errors. *Disuse* occurs when people ignore capabilities of automation and is a result of false alarms in the system. Lastly, *abuse* refers to inappropriate application of automation by designers without taking into account the consequences for human performance (Parasuraman & Riley 1997).

2.1.1 Driving and Automation

A driving task may be divided into several individual subtasks, classified into vehicle control, awareness of obstacles and navigation (Horrey et al., as cited in Strand 2012). Vehicle control refers to actions such as maintaining speed, manoeuvring the vehicle and positioning the vehicle. Awareness of obstacles refers to maintaining a safe path in the traffic and lastly navigation refers to planning the exact route of travel. The driving task is thus being shifted in between a continuum of manual and automated driving. As suggested by Strand (2012), introduction of varying degrees of automation in ADAS's can help in overcoming several safety issues. Although these systems share the same goal of making driving more safer, some of these might create new tasks for the driver to handle, such as glancing at displays, operating in-vehicle information systems which may interfere with the primary task of driving (Strand 2012). Increasing automation thus also leads to new concerns for safety.

2.1.2 Trust in automation

Lee & See (2004: p.51) define trust as 'the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability.' Here an agent could be automation which interacts with the surrounding system on behalf of the user to achieve user goals.

Ajzen & Fishbein (1980; Fishbein & Ajzen, 1975) as quoted in Lee & See (2004: p.53) suggest that 'reliance is a behaviour and trust is an attitude.' Attitudes are based on beliefs which help humans in forming meaningful intentions. Beliefs are influenced through experiences and they underlie trust.

Lee & See (2004) also discuss the relation between trust and the capabilities of automation. According to the authors, having an appropriate trust can avoid misuse and disuse of automation. To define appropriate trust in automation, Lee & See (2004) plot the relationship among calibration, resolution and automation capability (see figure 2).

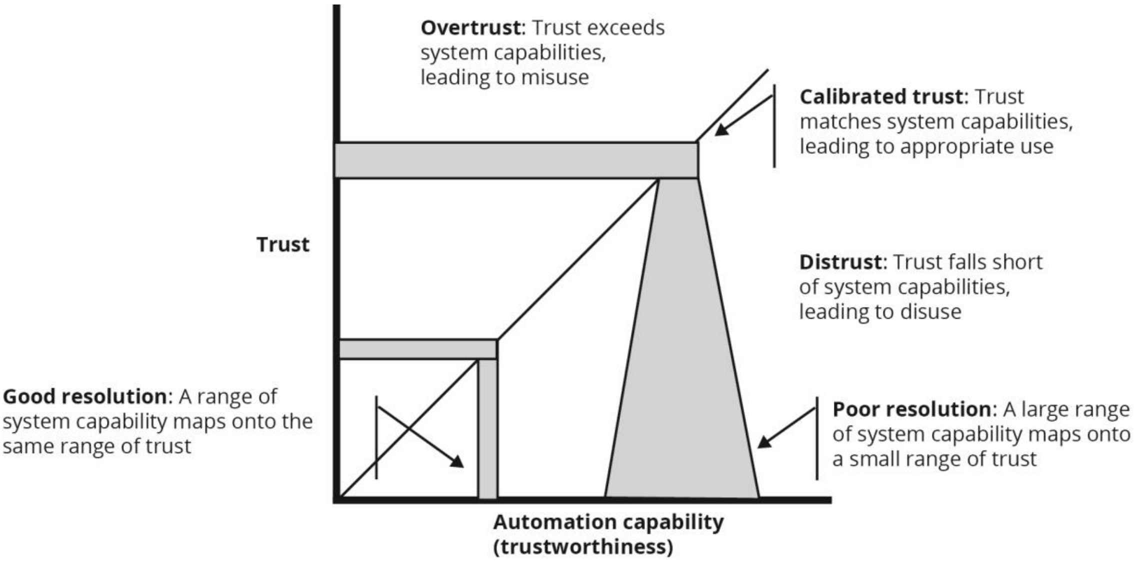

Figure 2: The relationship among calibration, resolution and automation capability in defining appropriate trust in automation, adapted from Trust in technology: designing for appropriate reliance, Human Factors 46(1), (p.56), by Lee & See (2004).

The range of trust is plotted along the X axis and capabilities of automation along Y axis. There can be three possibilities; either the system is subject of over-trust due to exceeding system capabilities, subject to dis-trust due to failing system capabilities or attains a calibrated trust due to matching system capabilities leading to appropriate system use which is represented by the diagonal line.

An operator complacency resulting in over-trust of a system could limit system performance even if the reliability in automation is high. Thus automated monitoring and reliable system performance may not go hand-in-hand due to automation-induced complacency (Parasuraman et al. 1993).

Cotter & Mogilka (2007) suggest that complacency in automation can also come into existence as a driver's mental representation of a driving task. Initially, the driver builds up a mental representation of interacting with the system with the help of the existing HMI in the vehicle. With continued exposure to different phases of interaction, the mental representation is refined and elaborated until it matches the actual system performance. At this stage the driver develops an appropriate level of trust which makes it easier for them to take actions to unexpected system malfunctions. The mental representation of the system may vary further over time according to driver behaviour, demands and time-pressure. These factors contribute to driver's calibration of trust which may possibly lead to attaining complacency.

Beggiato & Krems (2013) studied how initial information on automation capabilities could influence evolution of mental model, trust and acceptance of adaptive cruise controls. They concluded that the initial information provided to the drivers has a lasting effect on trust and acceptance of the system. This information is the initial mental model which is shaped by experience.

2.2 Advanced Driver Assistance Systems

An increase in desire to improve safety and comfort for the drivers has led to introduction of several advanced driver assistance systems in the automotive market. These systems also referred to as active safety systems, help driver to manoeuvre through demanding traffic situations (Lindgren et al. 2008). According to Carsten & Nilsson (2001) ADAS may be widely classified into information systems, advice and warnings, intervening systems and systems that support fully automated driving. Information systems can include navigation and those providing information on traffic conditions. The second category i.e. the warnings include lane departure warnings, collision warnings and lane assists. Adaptive Cruise controls and Stop and go functions are listed under intervening ADAS which can also be categorised as functions related to semi-autonomous driving and lastly the category where the driver is completely out of the loop is autonomous driving. With increasing number of intervening systems in vehicles, the role of driver from manual to supervisory control becomes more evident.

According to (Lindgren et al. 2008), these ADASs offer support to the driver at different levels. At the basic level, information is presented to execute better driving decisions. At the next level, these systems are capable of warning the driver of a risky situation to give them more time to make decisions. The third level of intervention involves the system not only warning the driver but also advising or guiding them through the situation. At the highest level of intervention, ADASs either take action independently or override the action of the driver.

2.2.1 Understanding Adaptive Cruise Controls

Adaptive cruise controls have been on the automotive market for a long time. Although being an intervening ADAS, these are also marketed as comfort enhancing systems by the manufacturers (Hoedemaeker & Brookhuis 1998). As stated by Strand (2012), ACC can be described as a distance measuring system which is capable of detecting objects ahead in the traffic. This allows the driver to maintain a set time interval and speed in a flowing traffic. For example, the driver can initially set a desired speed of 80 km/h and a time-gap of 3 seconds for the vehicle. Travelling at this set speed, the system detects another vehicle in front which is travelling at a speed of 50 km/h. Based on this information the system automatically decelerates and adapts the vehicle speed from 80 km/h to 50 km/h and follows the lead vehicle at a set time-gap of 3 seconds. The time interval ensures smoother acceleration and deceleration contributing to a more stable traffic flow (Hoedemaeker & Brookhuis 1998) and relaxed form of driving. Although ACC offers comfort to its user, it is important to note that the driver needs to continuously monitor system status and manoeuver the vehicle. These systems are thus not designed to deal with critical traffic situations and only act as a supporting system as the driver retains an active role (Larsson 2012).

It is possible to override the ACC functionality in two ways; either by applying additional acceleration while driving in a set speed or by applying brakes. These are typically allowed in commercial ACC systems (Nilsson et al. 2013).

The Volvo S60 Adaptive Cruise Control

The Adaptive Cruise Control installed in the Volvo S60 (2013) is an optional driver assist system capable of maintaining a set speed or a set time interval to the vehicle in front (Anon n.d.). The below figures depict the current ACC driver interface in the Volvo S60 model from year 2013.

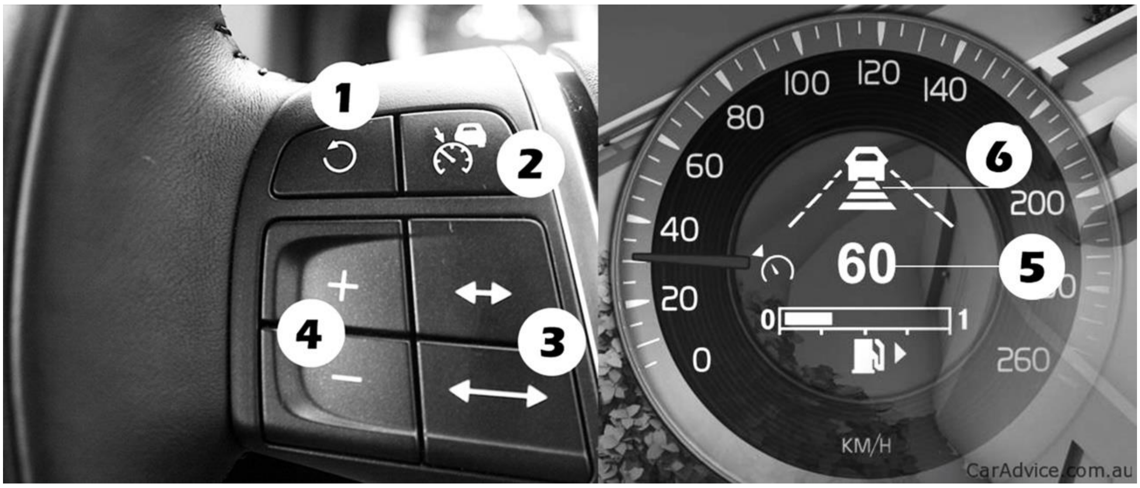

Figure 3: ACC steering controls and instrument cluster display. Adapted from (Davis 2012) and (Davis 2011).

Steering wheel controls:

1. With this the driver can either resume the previous settings or increase speed (set) by a factor of 2km/h.
2. This button is to switch standby mode on/off.
3. With this, the driver may increase or decrease the time interval to the vehicle in front.
4. After switching the standby mode on, the driver can use these to increase or decrease the current (set) speed.

Display:

5. This is the set speed.
6. These bars depict the time interval set by the driver for following a vehicle. 1 bar is approximately 1 second whereas 5 bars are approximately 3 seconds.

When symbol in the cluster display changes to, it means the system has detected a vehicle ahead and will now adapt its speed to the lead vehicle and will also follow the set distance.

For an effective use of ACC the drivers need to understand the capabilities of this technology (Seppelt & Lee 2007)**.** The limitations with the sensor and braking functions can cause the ACC to fail under several circumstances calling for driver intervention.

2.3 Human Machine Interaction

2.3.1 A simple human-machine system

According to Osvalder & Ulfvengren (2009), a human-machine system is a system which meaningfully integrates a human operator and machine. The human-technology system model presented by Osvalder & Ulfvengren (2009) comprises of humans and technology interacting together to accomplish a specific task.

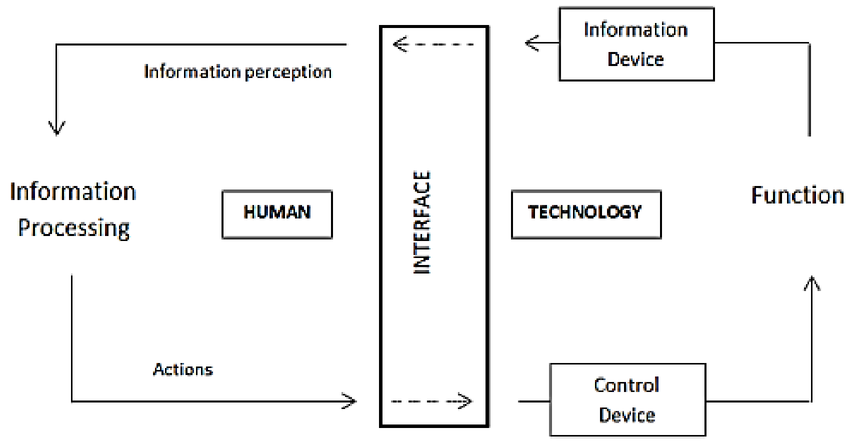

Figure 4: An overview of a human-machine system. Adapted from Osvalder & Ulfvengren (2009)*Work and technology on human terms* (p.342). Stockholm, Sweden: Prevent.

The technical system includes control devices such as buttons and knobs which facilitate execution of machine functions. The information device which gives a certain output for these functions also forms a part of the technical system. The operator in the model interprets the information from the technical system through a user interface in order to decide what actions are to be taken for a feasible interaction.

Vision

Vision is the most dominant sense in the human body accounting for almost 80 percent of all sensory impressions. The visual stimuli can only be detected within the field of vision which is 170 degrees measured horizontally in the front. To cover the entire surroundings, we have to turn accordingly. The human eye has visual receptors that are capable of recording various colours of light. Sensory processing of light includes several parameters such as contrast sensitivity, colour and dark-adapted vision, depth perception and movement detection (Osvalder & Ulfvengren 2009). Some of these parameters are briefly described below.

Colour vision

Humans have the capability to perceive colour which enables them to distinguish different objects in their surrounding based on the wavelength that is reflected to the eye. One might say that a difference in luminance could be sufficient to distinguish objects, but in cases where difference in luminance is very little, colour adds another dimension to perceiving such objects (Purves et al. 2001).

Visual search and detection of objects

Visual search is an everyday task of scanning our environment for a variety of objects in the crowd. It is the task of finding a target among various distractors (Verghese 2001). The ease of finding the target depends on how distinguishable the target is from the display. There are two types of searches; a serial search is when search time is proportional to the number of elements in the display, whereas a parallel search is when search time is independent of the number of elements in the display. Verghese (2001) gives an example of searching a tilted element among several distractors. If the tilt of the target is as large as 45°, one can easily locate the target making it independent of the display. In cases where the tilt is as small as 5°, the search time increases considerably with increase in number of elements.

Osvalder & Ulfvengren (2009) suggest that visual search of objects by humans is affected by two aspects: Conspicuity, i.e. how apparent the object is while scanning and secondly, the expectations of the observer as to what the target looks like or where it can be found. This clearly suggests the usage of bottom-up and top-down processing by humans while scanning spaces. This is the reason why it is recommended not to overload screens and displays with information that convey similar meanings as it causes delays in processing.

Design for visual information

Several design factors may be considered while presenting information visually. Some of the important ones include intensity, choice of colour, strength of lighting, contrast and angle of vision Osvalder & Ulfvengren (2009). Choice of colour for use in an interface can often depend on designers preferences. The authors suggest that the colour coding used must be consistent across the design and not more than four colours should be used in combinations in an interface. People associate colours with inherent messages in an interface. The following stereotypes are used for colour coding in the Western world (Osvalder & Ulfvengren 2009).

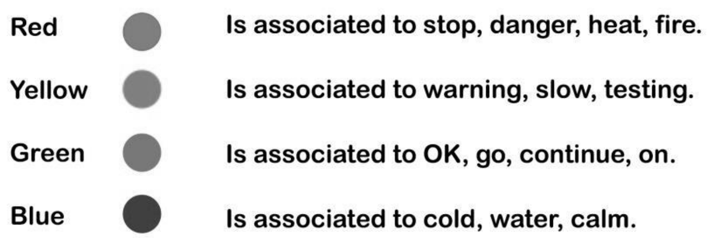

Figure 5: Colour coding in interfaces, *Work and Technology on Human Terms (p.391).*

Gibson's Theory of direct Perception

J. J. Gibson (1996) argued that perception is direct and a bottom-up process. The eye receives complex pattern of light reflected from a variety of surfaces. This pattern of light continually changes as we move through time and space.

During World War II Gibson worked on problems faced of pilot selection and testing. He observed that when pilots approached a landing strip, the desired landing point appeared static with the rest of the visual setting moving away from that point. Gibson called this 'optic flow patterns' (see figure 6). Gibson indicated that these patterns provide explicit information to the pilot about the plane's direction, speed and altitude. He asserted that perception and movement are closely connected. As we move forward towards an object particularly at a speed, the object itself appears to remain static while the surrounding tends to radiate away from the object.

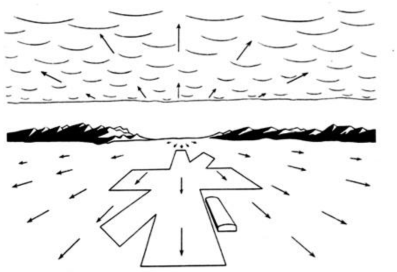

Figure 6: The outflows of the optic array in a landing glide. (McLeod 2007)

> 'Gibson believed that the information we receive through the senses is rich and complex allowing us to perceive the world directly. If the scene is static, near objects are larger and more spaced out whereas the farther objects are smaller and closer together. If we add movement, texture expands as we get closer and recedes again as it passes by. This invariant flow of texture is processed by our sensors automatically allowing us to perceive depth directly rather than having to infer it from cues.' (Farnan 2012)

Gibson's theory of visual perception had three important components;

1. Optic Flow Patterns
2. Invariant Features
3. Affordances

Optic Flow Patterns

Optic flow patterns have already been discussed. The flow of optical array will seem to be coming away from a point if the perceiver is moving towards it and vice versa.

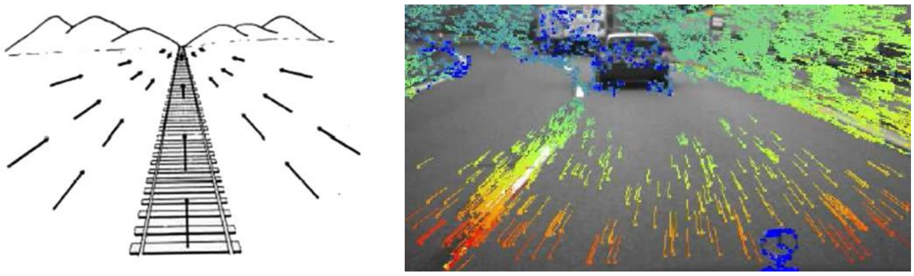

Figure 7: The Optic Flow pattern for a person. L – Person looking out of the back of the train (McLeod 2007), R- Optical flow pattern while driving (Eberli 2013).

Figure 7 indicates the direction of optical flow patterns if a person was looking out of the back of a train (Left) and also those when driving (Right). The image on the right is the result of a highly complex image processing algorithm developed by a German automobile company to study optic flow patterns in real time while using driver assistance and safety systems in cars.

The information is used to evaluate situations in their immediate environment such as predicting the position of other road users while driving (Eberli 2013).

Invariant Features
It is clear from our experiences that textures in the environment contract as we move away and expand as we move closer to an object. There is a pattern in these textures and are called Invariants. Invariants provide direct cue to perceiving depth. Gibson gives two examples of invariants; Texture and linear perspective.

Figure 8: Examples of invariants: Textures and Linear perspective (McLeod 2007).

The texture gradient gives the appearance of depth (see 'A' in figure 8). In 'B' the tracks appear to converge as they recede into distance. This is a linear perspective invariant.

Affordances
The last component is affordances. These are cues that aid perception. Optical array, texture gradient, relative size, relative brightness, height in visual field and superimposition are some of the important cues. Optical array and texture gradient have been discussed.

Relative size – Image of an object gets smaller if it moves further away from the eye.

Relative brightness – Objects that are brighter are perceived closer.

Height in visual field – Objects are perceived to be higher in the visual field if they are further away.

Superimposition – If there is one image blocking another, the first object is seen as closer (McLeod 2007).

2.3.2 Mental models
Mental models according to Norman (1980) are conceptual models that represent peoples understanding of how a product works. Norman (1980) suggests that different people may have different mental models of the same product or even a single person may have different mental

models about the operation of a product. Experiences shape how the user may interact with a product and it is these experiences that construct a person's mental model. Norman says that conceptual models play a vital role in providing understanding and predicting how things behave. These models help user in figuring out what to do when things do not go as planned while using a product. Having a better mental model about a product would mean a smoother prediction of effects of our actions.

2.3.3 Situation awareness

Endsley (1999: p.1) defines situation awareness as a person's 'perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future'. The SA error taxonomy proposed by Endsley projects different factors effecting SA at different levels. The three main levels are; Failure to correctly perceive information, failure to correctly integrate or comprehend information and failure to project future actions or state of the system. In addition to these three levels there also exist two other general levels, i.e. failure to maintain multiple goals and habitual schema. According to Endsley (1999)**,** SA errors could be induced by problems in system design or by errors in information processing at any of these levels. Endsley suggests that a failure to attend to the needed information in a system cannot be laid out at the feet of the operator and that it is an important function of system design. This means a systems-oriented presentation of information would make attention limitations worse for operators. Endsley also points out the relation between situation awareness and mental models. The failure to comprehend the meaning of information even though it is perceived correctly is directly linked with a poor mental model. The operators fail to associate information with relevant goals triggering wrong actions. Furthermore, in some situations, a poor mental model can make it difficult for individuals to correctly project future situations even if they are fully aware of what is going on in the system.

2.3.4 Mode errors

According to Norman (1980) mode errors occur when a system behaves differently from the state it is in, resulting in responses appropriate to one mode being executed by the user while in the other. In other words, when modes are not easily distinguishable in a system, the users may interpret the situation inappropriately. As cited in Strand (2012) when a system has more available actions than it has controls or displays and if it does not make the current mode visible to the user, this will be subject to mode errors.

2.3.5 Automated System Status

Lack of operator awareness and understanding of system states have resulted in increased threat to safety in process control and automated systems. In other words, the difficulties in processing information through control system interfaces have brought new challenges for the operators (Kaber & Endsley 1997). Poor system interface design is a direct contributor to these information processing errors where the difficulty to comprehend what is displayed has resulted in poor decision making leading to accidents (Kaber & Endsley 1997).

2.3.6 Continuous feedbacks while using ACC

(Seppelt & Lee 2007) suggest that it is important to provide the user with continuous information regarding the state of the ACC for appropriate reliance towards the system. Studies conducted by Dzindolet et al. (2003, cited in Seppelt & Lee 2007) on automation and reliance suggest that participants provided with appropriate information on why automation could fail led to more appropriate reliance compared to those provided with less or no information.

2.4 Interaction Design in Cars

Designing interfaces in an automotive setup is very much different from designing interfaces for desktops or mobile platforms (Schmidt et al. 2010). Several theories and principles on interface design were studied during the course of the project. The relevant ones are described briefly here.

2.4.1 Driving Task

A driving task in an automotive setup may be classified into three classes; primary, secondary and tertiary driving tasks (Tönnis et al. 2006). Primary task involves manoeuvring the vehicle. Secondary tasks involve switching turning signals or activating wipers. These tasks are for the safety of the driver, vehicle and the environment. Tasks that involve interacting with the entertainment and information systems fall under tertiary tasks (Kern & Schmidt 2009).

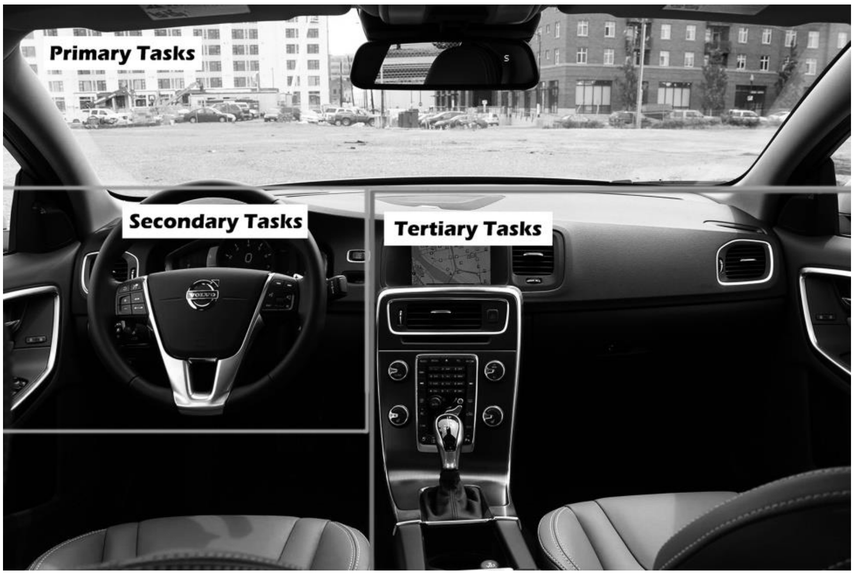

Figure 9: Distribution of primary, secondary and tertiary tasks in a driver cockpit. Adapted from 'A Survey of Challenges Related to the Design of 3D User Interfaces for Car Drivers' (Tönnis et al. 2006). Background image from Braun (2014).

Figure 9 illustrates how different areas can be allocated to different driving tasks in a cockpit. Tönnis et al. (2006) suggest that if access to a specific functionality is to be provided immediately, it is to be placed within the primary or secondary region. Primary tasks such as steering, braking and accelerating have a direct interaction with the traffic environment, and hence HUD's are recommended for displaying information from such tasks. For instance, while interacting with driver assistance systems, the driver provides user inputs within the secondary area but the feedbacks from these systems are to be essentially conveyed on the primary area (Tönnis et al. 2006).

2.4.2 Displays

Information about the status of a system is provided through displays. These are communicated through an operator's visual sense, auditory sense or sense of touch. According to *Ergonomics How to design for ease and efficiency* (cited in Persson & Rundqvist 2007: p.20) the "four cardinal rules" for displays are:

- *Display only that information which is essential for adequate job performance.*
- *Display information only as accurately as is required for the operator's decisions and actions.*
- *Present information in the most direct, simple, understandable and usable form.*
- *Present information in such a way that failure or malfunction of the display itself will be immediately obvious.*

Visual Displays

According to Tönnis et al. (2006) visual attention is crucial for driving since it is the main input sense for manoeuvring a car. Instrument displays are currently placed in the secondary area. They provide information such as current speed, oil temperature, turn signals, fuel levels and other warnings. These displays are more dynamic in the sense they are capable of presenting real-time status of the car to the driver intuitively. Several classes of instrument panel designs exist in the current market. Staudenmaier (2012) classifies them into three types. An additional segment of Head-up displays are also listed which is described in further sections.

Center add-on display

These types of displays have an additional display located at the centre between two gauges. The gauges convey the outputs of speed and rpm. Additional information such as fuel level, temperature and distance are displayed in the centre. In high-end cars, this space is used for bird-eye views, navigation, infotainment, night vision etc. (Staudenmaier 2012).

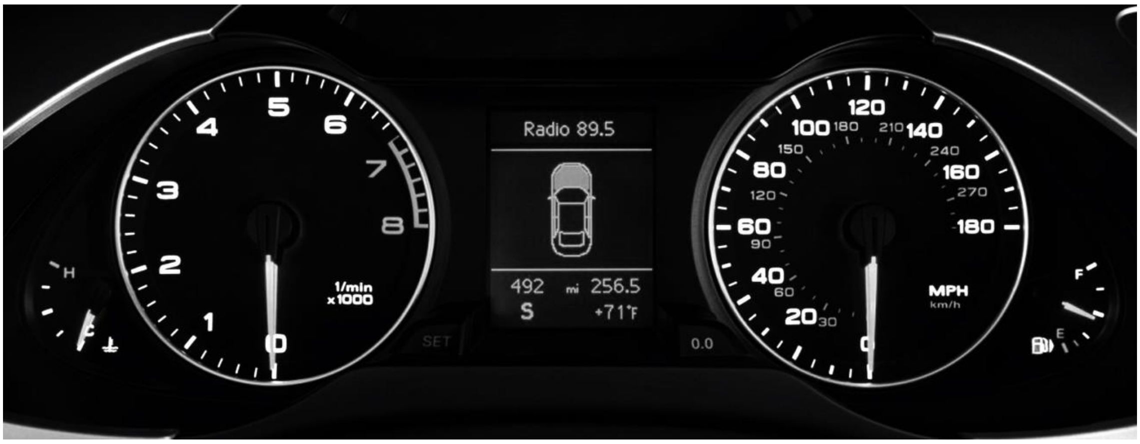

Figure 10: Audi A4 (2010) instrument cluster. Adapted from (2010 Auto 2.0T quattro Premium Instrument Cluster 2009). *Instrument Cluster - 2010 Audi A4 4-door Sedan Auto 2.0T Quattro Premium.*

Two Displays with central gauge

These types of panels provide extended graphical capabilities. The two digital displays on either side of the central gauge offer more flexibility in displaying information.

Figure 11: Ford Fusion Hybrid instrument cluster. Adapted from Huffman (2010) *Ford fusion hybrid instrument cluste*r.

Fully Configurable Cluster

These designs are fully software defined and provide complete flexibility for the user. Additional situation dependant information can easily be integrated with these types.

Figure 12: (Whitesell 2013) *2013 Jaguar XJ Instrument Cluster*

Head-up display

Other approaches to visual displays include head-up displays on windshields. These have a shorter glance time but can provide only minimal information since the current displays provide a field of view of approximately 6 degrees (Tönnis et al. 2006).

Figure 13: (Anon n.d.) BMW 6 Series Coupé Head-up display.

Auditory Displays

Audio displays are considered to be attractive communication channels for the drivers when there is minimal interference with visual channels. These may be used as informational signals or warnings (Tönnis et al. 2006). Warnings are usually conveyed along with another design artefact such as a flashing light or a written message to draw the attention of the driver and convey the desired message. In the context of traffic safety, warnings are considered effective to eliminate hazards and prevent crashes. A known advantage of audio warnings is their omnidirectional property which can alert drivers regardless of their visual attention. In case of ACC, alarms may be used when the system is operating outside its normal range (Tönnis et al. 2006).

Several researches have been conducted to understand what types of sounds are most effective for communicating information to the drivers. One type of existing warning notification is the non-verbal auditory warning. These are effective in situations when there is not enough time to convey the threat to the user through speech or verbal warnings (Edworthy 1994)**.** Edworthy also suggests two requirements to consider while designing a non-verbal auditory warning: firstly it needs to be audible but not too loud; secondly, it is much more effective if it conveys the attribute of a situation thus reducing the learning curve for users. If the warning's meaning is understood, these can cater to better levels of compliance.

Non-verbal warnings are widely classified into auditory icons and earcons. Auditory icons are sounds that are capable of representing a lot of information in a precise manner. These represent objects, functions and actions and are usually designed based on user's prior knowledge with several naturally existing sound sources and their corresponding causes (Dingler et al. 2008). Thus making them easier to learn, enabling automatic information processing (Fagerlönn 2011). Auditory icons, when used in warnings are also capable of communicating urgency of a situation based on the user's previous experiences with sound. This is capable of triggering appropriate emotional reactions based on the perceived urgency (Fagerlönn 2011).

Earcons are "abstract, synthetic tones that can be used in structured combinations to create sound messages to represent parts of an interface**"** (Brewster et al. 1993). With a combination of several appropriate earcons, it is possible to create a complex audio message for a combined set of operations. For instance, if there are two separate earcons for 'open' and 'file', these two could be combined to produce a single ‘open file’ audio message (Brewster et al. 1993). Earcons are also used as warnings in the automotive setup. However it could be the case that the listener is slow in interpreting the meaning of the sound leading to user error. With experience, this interpretation can become more automated and easier for the driver to recognise the sound (Fagerlönn 2011).

Multimodal Displays

Integrating several output modalities in interface design can help negate flaws of having a single modality interface. Visual displays are normally dominant in virtual environments. Auditory displays are only a level below and are useful when visual modality fails. For example, when a user’s visual perception is busy it is feasible to use audio feedbacks to convey warnings or messages (Basdogan & Bowen Loftin 2009).

An example for usage of multimodality in vehicles is one suggested by Tönnis et al. (2006) about the BMW parking assist. The initial audio version of the assist failed to provide distance estimation to nearby objects. This was later on improved by adding a visual component which displayed a bird’s eye view of the car and the environment. Obstacles were also highlighted in warning colours adding an extra perspective for the driver.

2.5.3 Warning System Design

Warnings are artefacts that represent situations to which they refer. These are designed to serve two functions – *alerting* and *informing*. The alerting function is provided by the signal word ‘Warning’ or other words such as ‘Caution’ or ‘Danger’ where each of these words represent different levels of hazard or risk. An alerting function could also be a combination of a signal word and other factors such as the colour and layout or an auditory warning that conveys urgency of a situation (Norén 2008). Informing functions are more explicit. These could be the messages that follow an alerting function which conveys to the user how the situation could be avoided. For example, a flashing battery icon followed by a warning message “Charge battery” in the dashboard of a car where the former is the alert and the latter is the informer. According to Persson & Rundqvist (2007: p.28) a warning when properly designed would include the following; ‘Indication of risk severity, Indication of the hazard, Consequences of not acting on the warning, Instructions that will reduce or eliminate the hazard.’

Chengalur, Rodgers and Bernard (2004) (as cited in Persson & Rundqvist 2007: p.20) list four general reasons for issuing a warning:

- *Inform the user or potential users of a dangerous situation.*
- *Inform users or potential users about the likelihood and/or severity of injury by the use or possible misuse of the product.*
- *Inform users or potential users how the severity of an injury could be reduced.*
- *Remind users of a danger at the time and place where the danger is most likely to be encountered.*

A warning is successful if it is detected, interpreted correctly and abided by. To impart a positive user influence in these three stages, appropriate human factors principles must be incorporated into warning design (Chengalur, Rodgers and Bernard, 2004 cited in Persson & Rundqvist 2007).

While designing a visual warning, which may be a combination of pictures, texts and graphical icons, the following factors may be considered (Persson & Rundqvist 2007: p.28):

- *Size* – Size of the warning must be relative to surrounding information. Reasonably larger size compared to the surrounding information is better.
- *Shape* – Shapes can draw an individual's attention to a warning message. Especially in the area of transportation where approximate meanings could be derived from the shape alone (e.g., Octogonal/Circular stop sign, triangular signs for speed limits).
- *Graphical icons* – Icons are capable of representing consequences that could occur and are effective when there needs to be a standard representation across different regions or demographics.
- *Color and contrast* – Color and contrast in warnings are equally important for proper visibility and attention. High contrast between text and background is preferred to aid detection of the warning sign. Black, white, orange, red and yellow recommended for signs.
- *Location* – It is plausible that the way people read information vary depending on the region. In the western culture text reads from left to right and top to bottom, hence recommended that the warning be presented accordingly (toward top or left), depending on the display design.

Warnings in vehicles are either static or dynamic. Low fuel levels, poor low tire pressure, engine stalls, battery failures etc. are some of the static warnings normally found in the instrument panel. Dynamic warnings on the other hand are situation or mode-based. This means the interface is capable of adapting to the situation or danger which reduces the information flow. The change in mode alone in the interface can alert the driver (Norén 2008).

Compliance is another crucial aspect in design and implementation of warnings. It may not always be the case that people comply with warnings. One of the main reasons quoted for this behaviour by Edworthy et. al. (1996 cited in Norén 2008) is that the perceived benefits of warnings are not outweighed by the perceived costs involved in complying with the warning.

As much as it is important to design a proper warning following human factors principles, it is equally important to evaluate these warnings for their effectiveness with users. A common mistake made by designers is the negligence shown towards understanding of user's mental model and the assumption that if the designer understands the meaning of the warning, then everyone else would (Norén 2008).

2.5.4 Design Principles for interface design

Principles for designing interfaces were looked into during the literature studies. Some of them are briefly described below.

Norman's Principles for designers

Norman (1980) suggested a set of design principles for designers placing an operator as the fundamental target in a human-machine system. Norman felt that designers used design principles that were presented to them by human factors experts at a later stage of the project after subsequent reviews rather than at an early phase. This was a major drawback while considering operator requirements while designing complex systems. The principles presented by Norman are closely related to research on mental models and information processing. Not all principles are listed here but only those which are closely related to the current work in hand are.

- The first principle suggests that

> ‘a designer need to establish a mental model to be used by the user and design the system around this model. All displays and operations are to be consistent with this model, minimizing the transformation required between the actual system and the user's internal mental model.’
>
> (Norman 1980: p.37)

- The second principle is regarding the provision for continuous system status to the user. Norman (1980) stresses the importance of providing an operator with continual system status of all states. Norman suggests that the design must allow the operator to continuously monitor and interact with the system in a meaningful way.

- Lastly, Norman suggests that it is useful if the system understands the user and is responsive to user needs. Referring to these as intention-based systems.

It is important to note that these principles are not specific to an automotive setup but are more general principles that may be referred to while designing user interfaces.

Design principles by Tönnis, M., Broy, V., & Klinker, G (2006)

Tönnis et al. (2006) suggest a set of general guidelines while designing interfaces for cars.

- Input from users should require minimal visual attention and have a short or no learning phase.
- The functionality of an input device must be fast and easy to understand. If the driver’s thoughts are focussed on understanding a new functionality while engaging in the driving tasks, this could lead to loss of attention contributing to accidents.

Designing by integrating user’s mental model into requirements

According to the German IUUI (Intuitive Use of User Interfaces) research group (as cited in (Loeffler et al. 2013: p.1)**,** ‘a technical system is intuitively usable if the users unconscious application of prior knowledge leads to effective interaction.’ Thus, designing an intuitive interface means finding a match between the user interface and the mental model of the user**.** Loeffler et al. (2013) argues that although several design guidelines are available for designing intuitive interfaces such as gestalt laws, affordances etc. they only provide vague advice for the design of user interfaces. This results in what is called as a “Design gap” between transfer of user requirements and final design making the outcome highly dependent on the experience of the designer. Loeffler, et al. suggest an IBIS method (German for design of intuitive use with Image Schemas) to bridge this gap while designing intuitive interfaces. The method uses image schemas to specify user’s mental models during requirements engineering activities. Image schemas are core cognitive structures arising from prior interactions and experiences. These are abstract, multimodal sensorimotor patterns that are retrieved from memory frequently throughout lifetime. These are processed unconsciously, hence making them interesting patterns for designing user interfaces (Loeffler et al. 2013).

Table 1: - Overview of the most important image schemas (Hurtienne & Israel 2007)

Category	Image Schemas
Basic Schemas	OBJECT, SUBSTANCE
Space	CENTER-PERIPHERY, CONTACT, FRONT-BACK, LEFT-RIGHT, LOCATION, NEAR-FAR, PATH, ROTATION, SCALE, SURFACE, UP-DOWN
Containment	CONTAINER, CONTENT, FULL-EMPTY, IN-OUT
Force	ATTRACTION, BALANCE, BLOCKAGE, COMPULSION, COUNTERFORCE, DIVERSION, ENABLEMENT, MOMENTUM, RESISTANCE, RESTRAINT REMOVAL, SELF-MOTION
Multiplicity	COLLECTION, COUNT-MASS, LINKAGE, MATCHING, MERGING, PART-WHOLE, SPLITTING
Process	CYCLE, ITERATION
Attribute	BIG-SMALL, DARK-BRIGHT, HEAVYLIGHT, STRAIGHT, SMOOTH-ROUGH, STRONG-WEAK, WARM-COLD

Hurtienne et al. (2007) indicate that these image schemas are schematic in nature and that they are not just symbols. These patterns exist beneath conscious awareness and could be represented visually, haptically, kinaesthetically or acoustically (Hurtienne & Israel 2007). Table 1 shows an overview of some of the most important image schemas as cited in Loeffler, et al. Consider for example the front-back image schema for spatial-relations. Here the concept of "time" is perceived on a spatial continuum from FRONT (future) to BACK (past**)** (Loeffler et al. 2013). Another example could be that of "quantity". People perceive this on a vertical continuum: UP (more) and DOWN (less). Another example could be that of "quantity". People perceive this on a vertical continuum: UP (More) and DOWN (less).

3. Methodology

3.1 Method of realization

The thesis was divided into three phases; the research phase, design phase and the evaluation phase. The outcome of the research phase was a set of requirements and design guidelines or criteria for generating concepts. The design and evaluation phases were tailored on a Simulator-based iterative design methodology (suggested by Alm 2007) and a usability evaluation framework (suggested by Harvey et al. 2011) respectively. The design phase will discuss how I arrived at the final design concept for evaluation. Lastly the experimental design and the usability evaluation framework used will be discussed under the evaluation section.

Simulator-Based Design

According to Alm, Alfredsson & Ohlsson (2007 as cited in Norén 2008), Simulator-Based Design is an alternative to traditional design methodology and is relevant when a driver is involved as a user in the operation. In SBD, the idea is to develop a virtual prototype and implement this in the simulator environment whereas the traditional way is to develop and implement a sub-system prototype in a test car for further evaluations (Norén 2008). The initial prototype in the SBD approach could be very conceptual and could take several iterative steps to arrive at the final design.

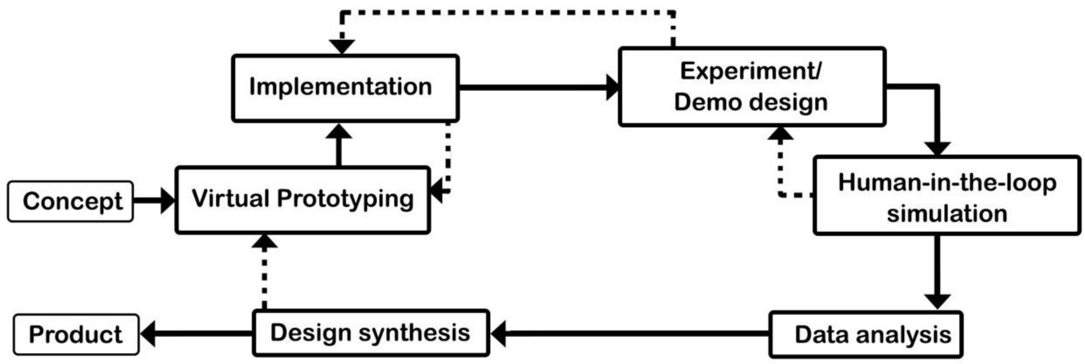

Figure 14: Main steps in SBD process, adapted from *Simulator-Based Design – Methodology and vehicle display applications* (p. 9), by Alm (2007). Dotted arrows indicate design iterations.

Figure 15 gives an overview of the various steps involved in the design and evaluation of the interface concept in this project.

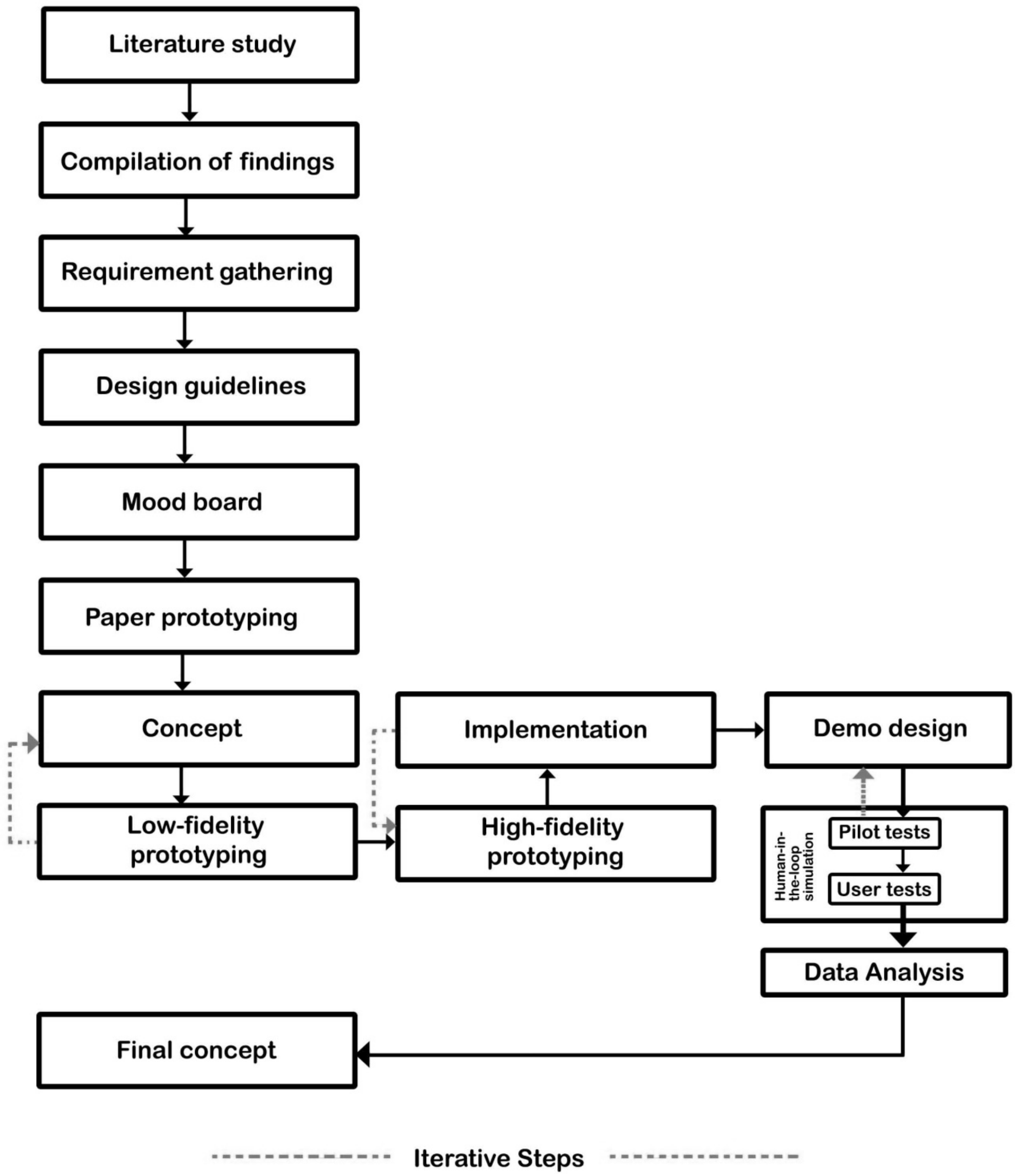

Figure 15: Flow diagram showing the steps involved in the realization of the concept. Dotted lines indicate design iterations.

3.2 Research Phase

The research phase involved studying relevant literatures and gathering requirements for the design. A majority of the requirements gathered were closely associated with the research findings of the SHADES project. Once the requirements were identified, list of design guidelines were proposed to further the work by generating interface concepts. This section will discuss the literature findings and implications. The section will conclude by listing a set of design guidelines for generating concepts.

3.2.1 Literature findings and Implications

It is clear from the literature studies that failures in the ACC system can degrade driver performance. When drivers face these failure situations such as inhibition of acceleration or braking functions while using ACC, which could result in imminent collisions, they tend to rely on their instant reflex of steering away from the threat (Strand 2012). As Strand (2012) indicate, designing intervention strategies to inform the driver of the current mode would be an ideal requirement under these conditions. Adding to this, the idea of keeping the system operational by providing adequate information regarding the mode of the system can also be considered. However, it is a hypothesis that these two requirements could depend on the criticality of the situation the driver is in. If it is a non-critical situation where the probability of a crash is low, the driver could be just informed of the mode of operation rather than adopting intervention strategies.

This hypothesis could be supported partly by the first focus group study conducted by Strand et al. which suggested that few drivers adopted strategies to override the system and take manual control of speed while overtaking another vehicle due to a delayed acceleration from ACC. Both studies clearly indicate that the system is not doing enough to convey the correct mode of operation to the driver. It also indicates that this adaptation strategy is due to the evolving mental models of drivers from ACC usage.

From the literature studies it was clear that system errors and driver behaviours during automation failures are a highlight of this research. From a driver's perspective, errors are either induced in user interfaces or appear in the electronics or mechanics of communication systems (Strand 2012). When a system failure propagates (see figure 16) the driver should be prepared to understand what needs to be done to avoid the consequences of these failures. This could be achieved if an interface is free from design flaws and conveys the situation appropriately to the driver.

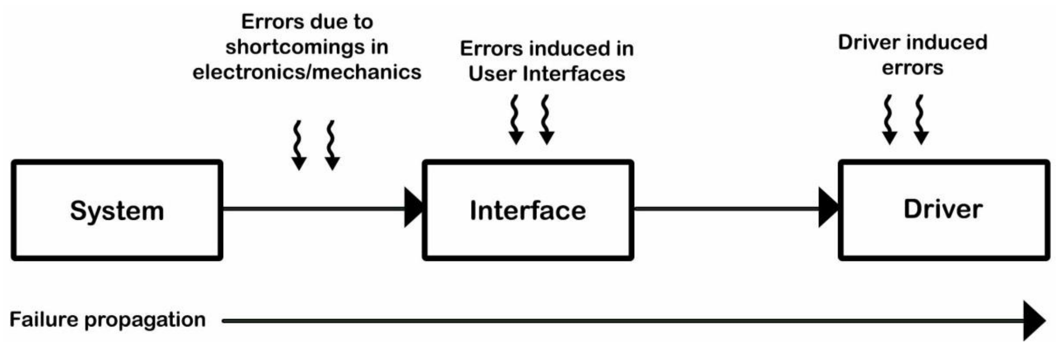

Figure 16: Propagation of failures in a driving context

The literature findings suggest that good background knowledge of user interface psychology is required to study the areas of system errors and driver behaviours. Also the understanding of HMI issues in a driving context is central in deciding how a set of requirement guidelines could be derived to design this human-machine interface for the driver.

Several HMI issues have been identified in a driving context. Issues in automation such as those related to trust, complacency, reliance, mental models, situation awareness and acceptance could be highlighted.

As Parasuraman & Riley (1997) indicated, whenever automation is involved in accidents, the concern is to see if the operator used automation appropriately or not. Lee & See (2004) assert that if an operator's trust matches system capabilities, this will result in appropriate use of the system.

A hypothesis could be derived from the findings of Cotter & Mogilka (2007) and Beggiato & Krems (2013). A relationship between trust in automation, risks and appropriateness of user's mental model (see figure 17) could be plotted. With time and experience, the mental models of the operators evolve and accordingly the trust and acceptance also evolve. The automation risk will be minimal when a calibrated trust is achieved. As indicated by Norman (1980), if the system is designed around user's mental model, this would reduce the learning curve by minimizing the transformation required between the actual system and user's mental representation.

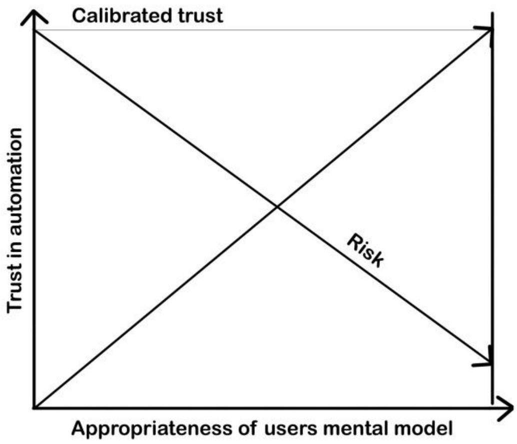

Figure 17: Relationship between trust, mental model and risk factors

Another correlation pointed out in the theory is that of mental models and situation awareness. Endsley indicated that operators fail to associate information with relevant goals triggering wrong actions due to poor mental models. This even causes poor projection of future situations in the system. This implies the need to apply mental model theories in system design. However, SHADES study suggested that different drivers had different mental models of the system and that they understood the ACC system differently. Hence, designing for appropriateness of mental models for a larger demography of drivers will be a challenging task even if the displays and operations as suggested by Norman (1980) are made consistent with this model.

Yet another interesting input from the study suggested by Seppelt & Lee (2007) is the importance of providing continuous information to the drivers regarding ACC system status. Displays should be designed as to fulfil this requirement for appropriate reliance. This can be closely related to the issue of mode errors suggested by Strand (2012).

3.2.2 Requirements

Before the functional requirements for the interface were listed, two major design parameters were decided based on the literature findings. These were;

- Design the interface by integrating user’s mental model.
- Design for situation awareness.

Based on these two parameters, the following functional requirements were listed;

- The interface will clearly communicate the mode it is operating in.
- The interface will clearly notify the user the type of failure and provide cues to contain it.
- The interface will be designed to facilitate users to develop a more correct mental model.
- The feedbacks will involve audio warnings prior to displaying visual information.
- The feedback will facilitate the failure to be contained within the stipulated time span.
- The interface will help the user anticipate the situation better.

An additional design parameter was decided after a mid-term presentation of the work with suggestions from the mentors. This was to

- Design the interface for non-critical situations.

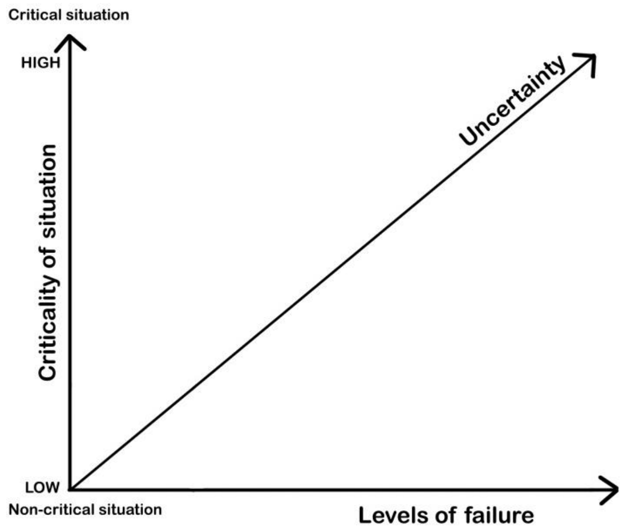

Figure 18: Relationship between criticality of situation and levels of failure.

The idea was to consider non-critical situations with lower levels of failures for the interface that would be developed. As shown in figure 18, adding more failure levels in the simulator scenarios with the initial design would have a higher uncertainty in the results and vice versa. Since it is an iterative design process, the design could be improved further by adding more failure levels and more critical situations in the future if needed.

Considering the literature on automotive interaction design, two modalities are considered for the design, the auditory and visual modalities. It was clear from the background studies that drivers provide inputs to the ACC system within the secondary area; however the feedbacks from these systems are essentially conveyed on the primary area (Tönnis et al. 2006). But Tönnis et al. also indicate that the secondary displays are more dynamic as these present real-time statuses of the car to the driver intuitively. So, this will be an attempt to implement the visual design within the secondary task area i.e. the instrument display.

3.2.3 Design guidelines

It was understood that the functional requirements listed were itself not sufficient to move forward with the concept generation phase. A more refined guideline was needed since the requirements provided an idea of what functionalities were to be implemented at the user end rather than how a design match with these could be achieved. As Loeffler et al. (2013) indicated, a "design gap" between transfer of user requirements and final design must be avoided as much as possible.

Two questions were posed again at this stage to derive a set of design guidelines for concept generation;

1. *How to fit the visual nature of the interface with the functional requirements identified?*

It was decided that the concept of image schemas and similar stereotypical representations would be used to design this interface. The idea was to couple image schemas with abstract concepts relevant to the functional requirements. For example, the concept of "importance" could be linked with the distribution of alerting functions in the interface which could be then coupled with an image schema such as "Important information is to be placed at the centre and unimportant, in the periphery." The following guidelines were chosen:

- Use of colour coding where possible
- Use of concept of importance while placing information in the interface
- Use of concept of time while designing for depth

Please note these guidelines were randomly chosen in relation to a set of existing image schemas listed in the theory. The choice was made with an assumption that these would fulfil the functional requirements specified. Also, since this is an iterative design process, the freedom was there to re-consider these guidelines as they could always be altered according to feedbacks from users in the later stages of design.

2. *How the concept could be integrated with the existing design elements in the instrument display?*

There are two aspects in the design. One is the warning design concept that is being developed and the other is the design of the instrument cluster display itself. It was clear that the integration with the warning design should also provide the driver with the possibility to view all the basic information in an instrument display i.e. speed, flashers and other warning symbols. With respect to ACC, acceleration and braking are important functions and hence conveying the speed variable intuitively to the drivers was also important.

Even after listing design guidelines, it was still unclear how to advance to the design phase due to the ambiguity of the requirements listed. So, in order to bring more clarity to the design phase, it was decided that two design decisions will be made in sequence;

- In the first stage of design, it will be decided how the information will be distributed in the interface.

- In the next phase it will be decided on how the information will be presented and conveyed.

Here, both the decisions will be based on the design guidelines, picking the appropriate guidelines while making these decisions.

3.3 Design Phase

The design phase began with the concept generation stage and concluded with the high fidelity prototype set up for evaluation in the simulator. A series of design iterations were made during the design phase. In short, the design phase progressed from a simple paper prototype, developing this into a desktop prototype and finally implementing the high-fidelity prototype in the simulator with several iterations between these stages.

Integration of the visual warning with the instrument display design is a highlight of this phase and the ACC instrument display of the Volvo S60 (see figure 3) was taken as a reference to understand existing ACC symbols used in a car.

3.3.1 Concept Generation

The initial phase in the design process is concept generation. This is a phase where several ideas are generated prior to choosing a design as a final prototype for evaluation. According to Ulrich & Eppinger (2012: p.118), a concept is 'an approximate description of the technology, working principles and form of the product.'

As stated in previous sections, two modalities were chosen initially for the concept; visual and auditory, with more importance given to designing the visual modality. The concept generation began with the design of the visual modality. The initial challenge was to decide upon the layout of the instrument display that would effectively fulfil the requirement of integrating the warning design concept. In other words, to answer the question on how information could be distributed effectively.

Design direction

The first phase in generating the layout concepts was choosing a design direction. At this stage two extremities were considered. Whether the overall display design had to follow a more traditional form or a futuristic form as far as the aesthetics were concerned. A set of keywords were populated that closely represented both forms of design (see Appendix 3).

Mood board

Once the design direction was decided, a mood board was populated with the theme under consideration (see Appendix 4). Mood board is a collection of pictures, texts or textures representing the requirements of the solution based on the research made. These can act as a reference point for generating concepts based on a specific design theme (Wyatt & May 2014).

Sketching

The next step was to brainstorm and sketch ideas based on the chosen design direction and pictures populated in the mood board. 'Sketches are a fast and inexpensive medium for expressing ideas and evaluating possibilities with them' (Ulrich & Eppinger 2012: p.218). Several sketches were brainstormed (See Appendix 5). From the literature, three most common design layouts out instrument displays were identified (See Appendix 6).

Concept Selection

As indicated by Ulrich & Eppinger (2012: p.144), 'concept selection is an integral part of a product development process.'

At this stage of the project, all three layouts (see Appendix 5) were evaluated with the design guideline of placing information with concept of importance. Layout 1 (see figure 19) was considered appropriate to move forward with this guideline. Note that not all guidelines could be considered as the concept was still at an early stage and hence the decision to choose this layout could have been vague.

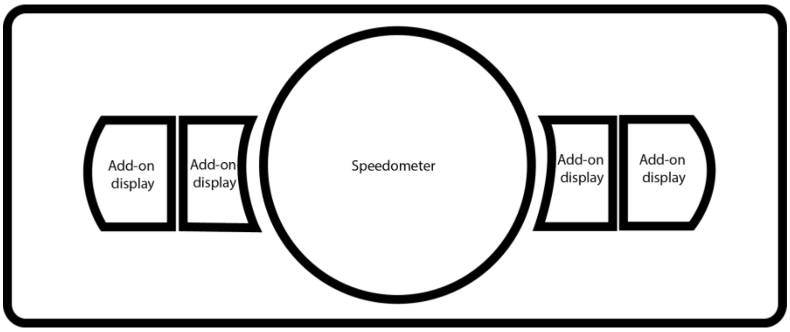

Figure 19: Chosen instrument display layout

The decision on the choice of layout and the choice of sketch was made concurrently. One sketch from a series of sketches (see Appendix 5) was chosen which would closely match the chosen layout and the guideline for concept of importance while placing information in the visual interface (see figure 20).

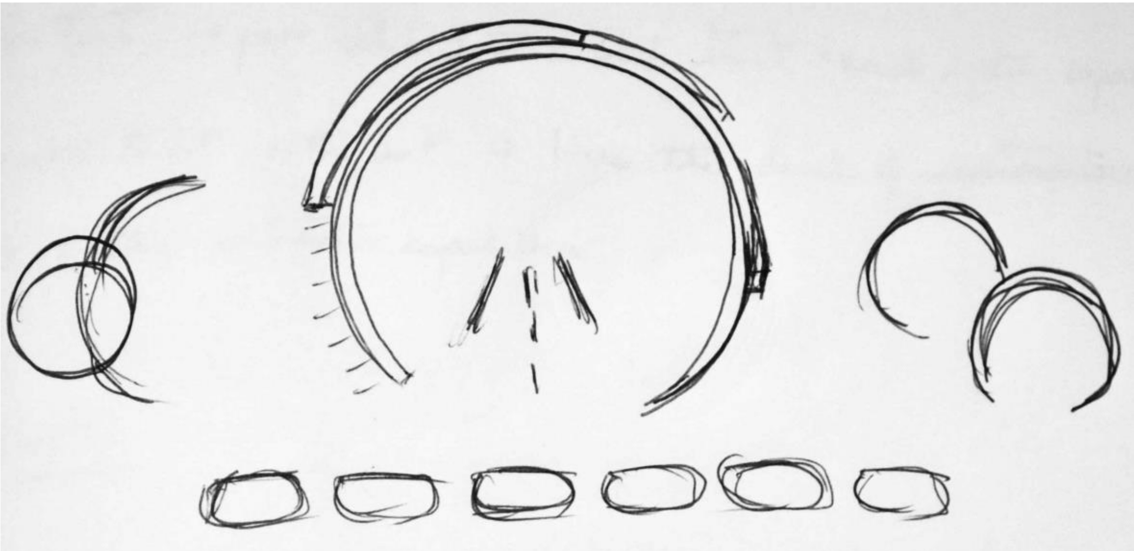

Figure 20: Chosen sketch

Once the sketch was chosen, the need to classify information while in a semi-autonomous drive mode became more evident. This gave a better picture of how information could be arranged in the chosen layout based on the design guideline. The classification was purely based on the understanding of the SHADES literature findings.

Table 2: Classification of information while in semi-autonomous drive mode.

Classification while operating in semi-autonomous drive mode	
Secondary information	Primary information
Fuel level Temperature Transmission modes Standard warning symbols Flashing indicators	Warning information System mode information • ACC Active Mode • Failure mode • Manual Mode Operating mode information • Speed keeping • Distance keeping Speed

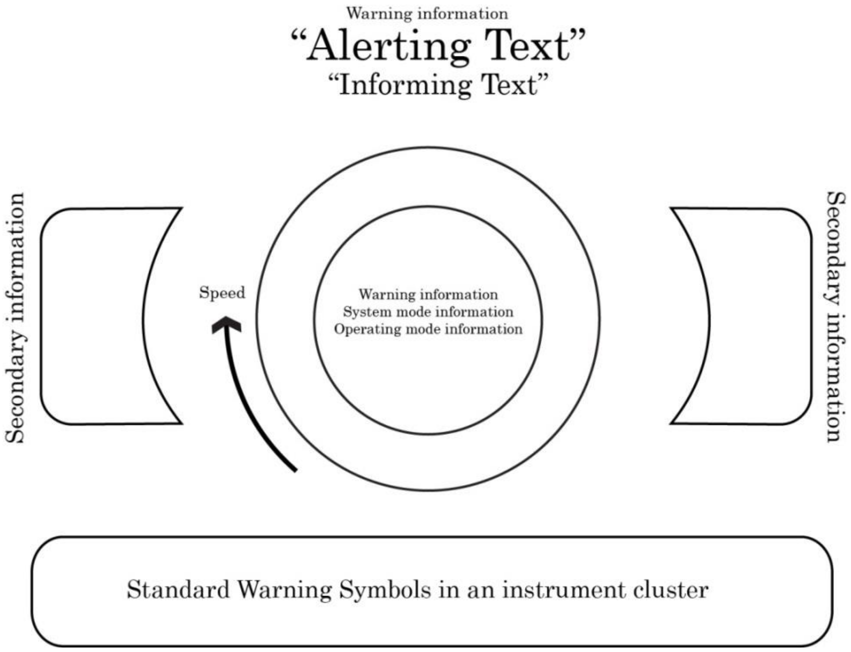

Figure 21: Distribution of information according to Centre-Periphery image schema.

The above figure shows the distribution of information according to the image schema CENTRE-PERIPHERY. The primary information listed is placed in the centre. As we move towards the periphery the secondary information are distributed. An attribute schema was also used for displaying text. In a group of information, the texts that are BIG in size are viewed first than those that are small. The priority is for the BIGGER texts.

Table 3: The chosen space and attribute schemas for presenting information in the layout

Category	**Image schema**
Space	CENTRE-PERIPHERY
Attribute	BIG-SMALL

Paper prototyping

Since the decision on how the information would be distributed was made by evaluating the sketches**,** it was time to decide on how the information will be conveyed to the driver. This started off by sketching a paper prototype with potential warning design suggestions by including possible driver interactions during experimental scenarios. Paper prototypes are a paper version of the interface which could be used in the early stages of prototyping to generate and improve design ideas and conduct internal interface reviews (Snyder 2003). At this stage it was also important to consider what type of events would occur when in the scenarios and what modalities could be included for the warning function.

3.3.2 Emotion Concept

The first concept prototype was called the emotion concept. The driving scenario considered at this stage of concept generation was very vague. It was assumed that the ACC cruising speed would be set initially at 70 km/h and the time interval to a lead vehicle would be set at 3 seconds.

When the driver accelerates to the set speed, a ‘speed-keeping activated’ notification is displayed at the centre of the interface. The driver is in a car-following scenario when an acceleration failure is injected. At this stage, an audio warning is conveyed to the driver which is followed by changes in the design of instrument display (see Appendix 7). The visual warning alert is conveyed through several means;

- The layout colour changes to red (failure mode) from blue (semi-autonomous mode).
- A pictorial representation of a facial expression in the centre of the display.
- An exclamatory symbol which fades in and out (flashes) with the facial expression.
- Lastly a pictorial representation of a braking action to request the driver to take control of the longitudinal function.

When the driver applies brakes, there is again a change in colour of display, which now turns into Green and informs the driver to either Press the RESET button to reset ACC or to continue driving in manual mode.

This concept was just an initial thought on in what way the warning concept could be integrated with the instrument layout design. The idea here was to connect emotions of users by using schemas of facial expressions that would convey the different modes of the system. Also the colour coding had two purposes; to convey the mode the driver was in and to convey the warning.

The emotion concept at this stage had certain limitations. A few design elements such as the colour coding used for conveying different modes and use of symbols as alerting functions were looked into for iterations. The idea of designing for emotions used in the concept, although interesting, was not worth researching into at this stage of the project since it was never considered during the background study. Another limitation thought to be the reason for not choosing to move forward with this concept was the difficulty involved in prototyping this concept for the simulator due to limited time and technology requirements. However, a key reason in making this decision was related to the use case scenario considered. The scenario was very inexplicit while sketching this prototype since the design was still at the early stages. It was clear that considering a very unambiguous use case scenario prior to prototyping was very important at this stage of the project.

3.3.3 Scenario

Before proceeding into iterating the emotion concept, a driving scenario was explicitly described which would help identify what the user goals are and what user interactions are expected of these goals in the scenario which could then be connected with what information needs to be conveyed to the driver to encourage these interactions.

The following was the scenario considered at this stage:

The driver accelerates to 70 km/h. At this point the ACC is activated and is in speed keeping mode. The driver is free of longitudinal control and only needs to take care of lateral control. The driver encounters a vehicle ahead after a few minute drive with ACC. The ACC now switches to distance keeping mode with a set time interval of 3 seconds. The lead vehicle brakes several times during the car-following scenario and comes to a complete stop. The ACC responds by braking automatically. In one of those stop-and-go scenarios, there is a complete brake failure and the ACC fails to engage and the driver has less than 3 seconds to avoid collision with the lead vehicle.

The driver goals and driver interactions were listed based on this scenario to understand what information needed to be conveyed to encourage these interactions.

Table 4: Relationship between driver goals, driver interactions and information to be displayed.

Driver goals	Driver interactions	Information to be displayed
Activate ACC (Semi-autonomous mode)	Accelerate to 70 km/h	ACC Active Speed keeping activated
Follow vehicle	None	Distance keeping activated
Disengage ACC (Manual mode)	Apply brakes	Manual mode Active
Respond to the failure	Type of response to the warning function	ACC Failure

3.3.4 Iteration 1- Desktop concept

The emotion concept was iterated again with this information. The existing paper prototype from the emotion concept was referred and a new prototype created with improvements in the concept (See Appendix 8). As you can see from the prototype,

1. An initial home-screen was added where the display prompts the driver that they are in semi-autonomous drive mode and whether they want to choose a pre-set display setting for the instrument cluster.
2. The driver selects the display (VISES) for semi-autonomous drive mode.
3. The driver confirms the speed and distance setting.
4. The driver begins the scenario. Accelerates to 70 km/h. An audio notification and a flashing ‘set-speed’ symbol along the circumference of the speed dial confirm ACC has been activated.

5. An ACC failure is encountered during the scenario. An audio warning is conveyed in addition to alerting and informing text notifications. At this stage, a driver response is expected if the warning is detected.

Even though several changes were made in this concept, the clarity in what information was to be displayed in the interface was still very ambiguous. Hence, it was decided to prototype this concept with possible animations and interactivity in a desktop setup.

Adobe Illustrator was used as the design tool and Microsoft Expression Blend for adding interactivity and animation. More information regarding these tools can be found in Appendix 2. The desktop prototype is shown in Appendix 8. Few additional design elements from the existing paper prototype were added in this concept considering the scenario. A pictorial representation of the braking action from the emotion concept was also used here (see screen d, Appendix 8) to convey to the driver what needed to be done when the failure was detected. The pictorial representation was an animation representing the braking action. Once the brakes were applied, the ACC switched off and the interface changed to Manual drive mode (see screen e, Appendix 8).

Audio notifications
Audio notifications were also added at key intervals in the interface. An earcon to convey that the ACC had been activated (speed keeping and distance keeping activated) was used. During the course of failure, an auditory icon was used to alert the driver of the situation. The icon was a soundtrack from the movie *'Psycho'* (freeSFX n.d.). This was based on the idea that existing sound sources based on user's prior knowledge would make the driver easier to learn the meanings of these warning sounds. Another purpose was to direct the driver away from the road towards the source in the instrument cluster as the driver now seeks to gather more information regarding the warning.

Alerting and informing texts
The information regarding the warning was provided through alerting and informing texts. Since the driver had a very short duration to act, the information on what had to be done to avoid a failure situation or to turn off the ACC was highlighted. The alerting text "ACC FAILURE" was displayed on top of the informing text (see figure 22).

Figure 22: Alerting and informing texts.

Symbols
Additional symbols were also designed to convey the mode of operation and warnings. These were placed in the region allocated for warning symbols in an instrument display. Another set of ACC symbols for speed and distance setting were also designed by taking the Volvo S60 display as a reference.

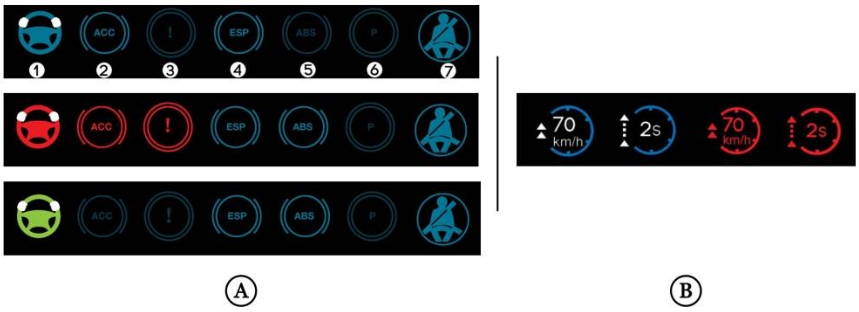

Figure 23: A: Warning symbols used in the design. B: Re-design of set-speed and set-distance symbols.

As you could see from the figure 23, Symbols 3-7 were all standard warning symbols used in a vehicle such as:

ESP – Electronic Stability Program, ABS – Anti-lock braking system, P – Parking brake, Seatbelt warning.

These symbols were solely used for the purpose of aesthetics and had no connection with the ACC warning.

The intention of designing symbol 1 and 2 was to convey the mode the driver was operating in. For instance, in the first series of symbols, '1 &2' intended to convey the message 'Semi-autonomous drive mode'. With the steering symbol, the purpose was to convey that the lateral control of the vehicle was still necessary in this mode.

The colours of these symbols vary according to the situation. When there is a failure detected, these change to red. Lastly when in manual drive mode, symbol 2 disappears and symbol 1 turns into green conveying ACC has been switched off and steering needs to be in complete use. Symbols representing set-speed and set-distance were also re-designed (see 'B' in figure 23).

Design for depth

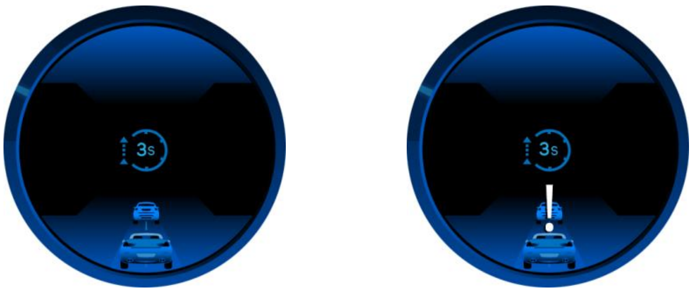

Figure 24: Front-back schema for adding depth

Another image schema used for adding depth to the design was 'front-back' schema where the concept of "time" is perceived on a spatial continuum from FRONT (future) to BACK (past). The simulator vehicle and the lead vehicle were added with a perspective view. If the simulator vehicle disregards the set distance, a notification appears between the two vehicles.

The concept was presented for review with the mentors before prototyping this for the simulator. It was known after the review that one of the guidelines had been neglected, i.e. designing for non-critical situations. The criticality of situation considered in the scenario was high since the driver had less than 3 seconds to avoid a collision with the lead vehicle. This was a major drawback in the design and had to be re-done. Also it was suggested that the symbols and the audio notifications are evaluated before prototyping them for the simulator. Hence iteration had to be done.

3.3.5 Iteration 2 – Simulator prototype

The existing desktop concept was now iterated considering the criteria for non-critical situations. A new scenario was considered before proceeding to re-designing the concept. At this stage the symbols were also evaluated. It was decided that the evaluation of audio notifications will be carried out when simulator experiments are performed with participants.

Scenario

The new scenario was similar to the previous scenario considered (see section 3.3.3) except that a braking failure was injected not when the lead vehicle braked but when both the cars were on the move. With this, the driver had enough time to possibly interpret the situation and act accordingly.

Icon intuitiveness test

The symbols designed were evaluated by adapting the procedure used in an icon intuitiveness test suggested by Nielsen (1995). Icon intuitiveness test is a methodology used to assess the degree to which a graphic chosen for an icon represents the intended concept. The users are asked to suggest the best guess as to what the icon is supposed to represent. Several alternative concepts are tested and a few promising ones are chosen (Nielsen 1995b).

In this project, an online survey was performed instead of asking participants in-person as to what each symbol represented for them. The reason for using a survey was to get a response from a larger audience and the lack of time to evaluate these with individual users. In total, 26 participants took part in the surveys who were employees from VTI and SAFER, Vehicle and Traffic Safety Centre at Chalmers. The results of the survey can be found in Appendix 9.

The re-design

Several changes were made in the design to adapt it more towards a non-critical condition. The presentation of visual warning design (screen d, Appendix 8) and the auditory icon used to convey the warning had to be changed since the existing design was more inclined towards more critical situations.

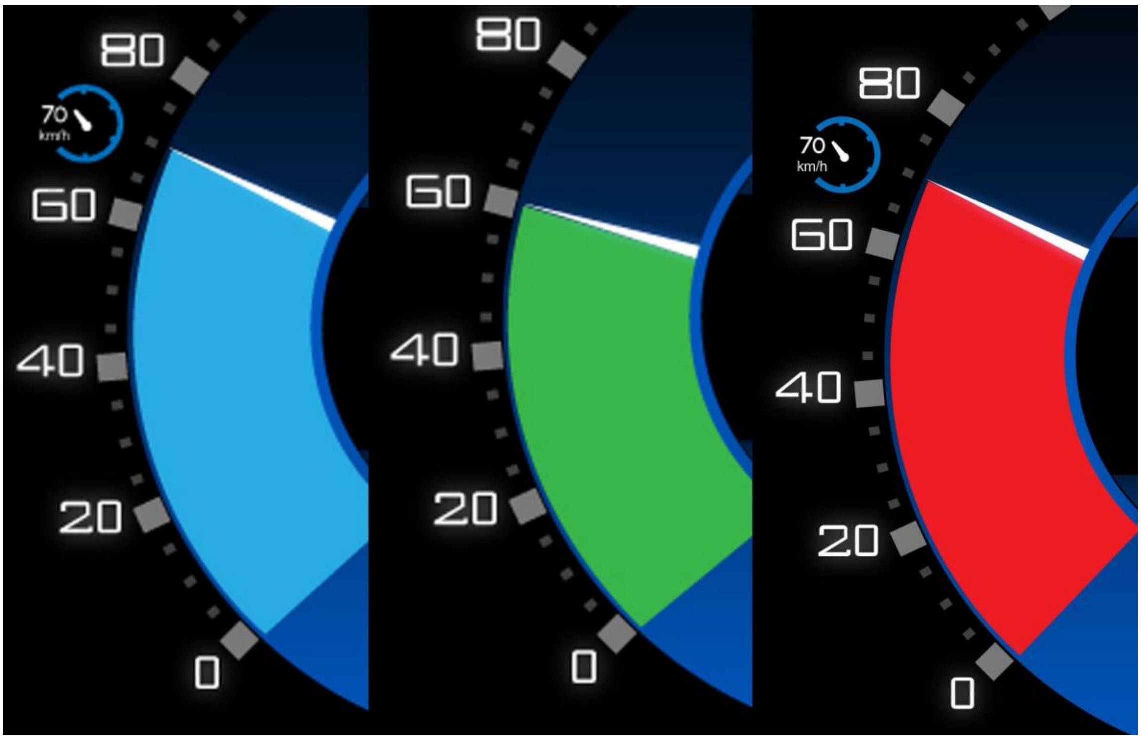

Figure 25: Colour coding to convey different system modes

This time a high-fidelity prototype was developed in *Processing* (see Appendix 2) for the simulator with UDP communications setup with the simulator hardware.

High-fidelity prototyping is a way of creating realistic computer-based prototypes of the concept which can take us as close as possible to a true representation of the interface. These prototypes are effective in collecting data related to human performance and can be used for demonstrating the actual product to the users (Usability.gov n.d.).

Apart from the prototype, scenarios were also setup in the simulator which will be discussed in forthcoming sections. The highlight of the re-design was the colour coding used to show the speed and the system mode in which the driver was operating in. The blue represented the semi-autonomous mode, green manual mode and red the failure mode (see figure 25). Speed keeping and distance keeping modes were displayed along the set-speed value and in the centre of display respectively. The symbols were updated with the results from the survey. Also it was decided that the steering symbol (see figure 23) will only be highlighted during the semi-autonomous and failure modes as it was very obvious that the driver would use the steering while in manual mode. There were also diverse opinions regarding these symbols used to convey the modes as a few respondents to the survey concluded they did not understand what its purpose was (see Appendix 9). The auditory icon was changed to a more apparent warning notification used in cars. The earcon remained the same. The idea to include a home-screen and the possibility to confirm the speed and distance settings before running the scenario were discarded from this concept due to the difficulty in prototyping for the simulator.

Before proceeding into conducting pilot tests in the simulator, the concept was once again evaluated with the requirements listed by running an experimental scenario in the simulator.

The requirement of conveying audio warning prior to displaying visual information had to be re-considered. Since the warning had to be conveyed instantly once the failure was injected, it was important that both modalities were conveyed together with the visual warning being displayed for a longer duration. A re-consideration was also made on the distribution of information based on schemas. The secondary information was moved further to the periphery (see figure 26) and an ACC status notification added (see Appendix 10) beside the speed info.

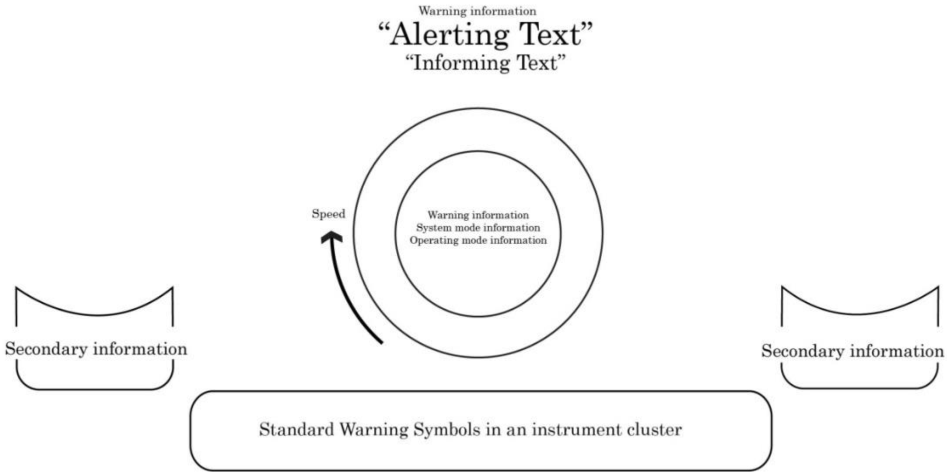

Figure 26: Re-distribution of information according to image schemas

Another thought was to add an artificial optic flow pattern (see figure 7) within the instrument display to help the driver judge the immediate environment while driving even when they are glancing on the interface. These patterns were implemented as a particle system (See figure 44, Appendix 10) flowing in the z axis or towards the driver. The speed of these particles was adapted to the speed of the car quite similar to the natural optic flow patterns perceived directly by the driver.

Also an additional alerting and informing text was added for non-critical situation (see figure 27). The final simulator prototype can be found in Appendix 10.

Figure 27: Alerting and informing text for non-critical situation.

3.4 Evaluation Phase

The evaluation began by implementing the demo design in the simulator. Pilot tests were conducted in the simulator prior to testing the demo design with recruited participants to re-check the scenarios, apparatus and the complete procedure of interacting with a participant. Even though the demo design was adapted for non-critical situations, three scenarios were considered. A non-critical scenario and two critical scenarios where one of the critical scenarios had warning function implemented. The purpose was to gain further knowledge on whether the driver was capable of detecting the automation failure with the help of the interface function during non-critical conditions and extending this understanding to designing for critical conditions by comparing results from both scenarios.

3.4.1 Usability Evaluation

Usability evaluation is used to assess the compliance of a system's human-machine interface with various usability criteria which are specific to the system's context of use. These evaluations can predict the likely success of a product in the market (Harvey et al. 2011).

Usability evaluation tools for evaluating the interface were chosen based on the methodology suggested by (Harvey et al. 2011). Although this methodology was for evaluating IVIS in a car, the idea was to see if the procedure could be adapted for evaluating the demo design under consideration in this project. The authors suggest that before conducting any usability evaluation, it is desirable to follow three principles so that preliminary information is clearly defined. These are:

Defining the task-user-system interaction

The task, user and system are the three factors that predict the usability of a system. It is important to determine how these three factors will be represented in the evaluation as per the needs of the evaluation.

Considering the interface for ADAS's, the design must provide enough information for the driver to have control over the primary tasks of longitudinal and lateral control of the vehicle. The driver must be able to process the information presented. The success of the interactions between the driver and the design of the interface developed will determine the success of usability in the system.

Defining the context of use

Context is another factor that partly predicts usability. Certain attributes of usability is dependent on the circumstances in which a system is used and these factors need to be defined.

Several contextual factors could be considered in case of IVIS as suggested by Harvey et al., such as dual task environment, range of users, environmental conditions, training provisions, frequency of use and successful uptake of the system. These factors are comparable with the factors that influence usability of interfaces for notifying failures in ADAS's.

Defining the usability criteria

The evaluators need to be aware of the aspects of interaction that are relevant to usability. Harvey et al. suggest that a usability criteria that defines a target level of usability need to be developed. The criteria for usability for IVIS were defined in relation to the context of use factors (see figure 28).

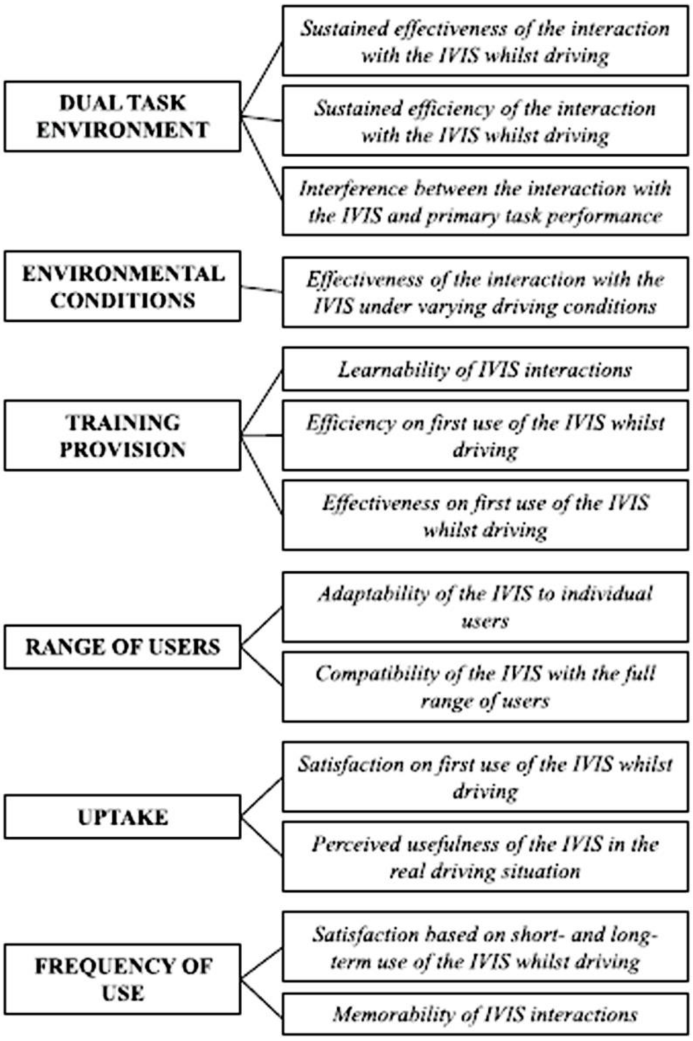

Figure 28: IVIS context of use factors and usability criteria by Harvey et al. (2011) *Applied Ergonomics 42 (2011) 565.*

The usability criteria for the system under consideration in this project are defined similarly. These criterions are listed in figure 29.

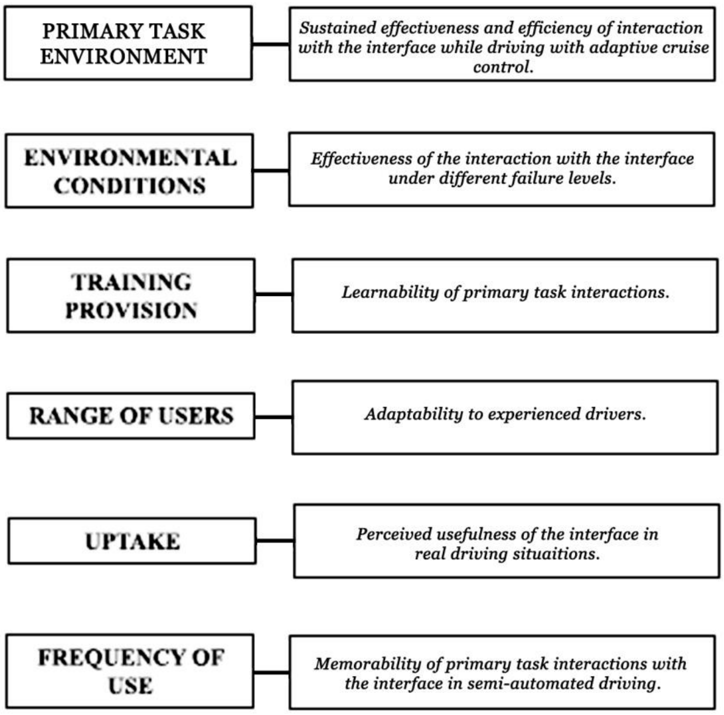

Figure 29: Context of use factors and usability criteria for the interface developed.

Once the preliminary information is clearly defined, a set of evaluation methods are to be selected according to their suitability to the usability criteria for the system under consideration. Harvey et al., propose four principles as a guide for selecting the right method for evaluation; the type of *information required, the stage of application, the resources available and the personnel involved*.

In the framework developed by Harvey et al., thirteen methods were picked which were considered appropriate for evaluating IVIS (see figure 30).

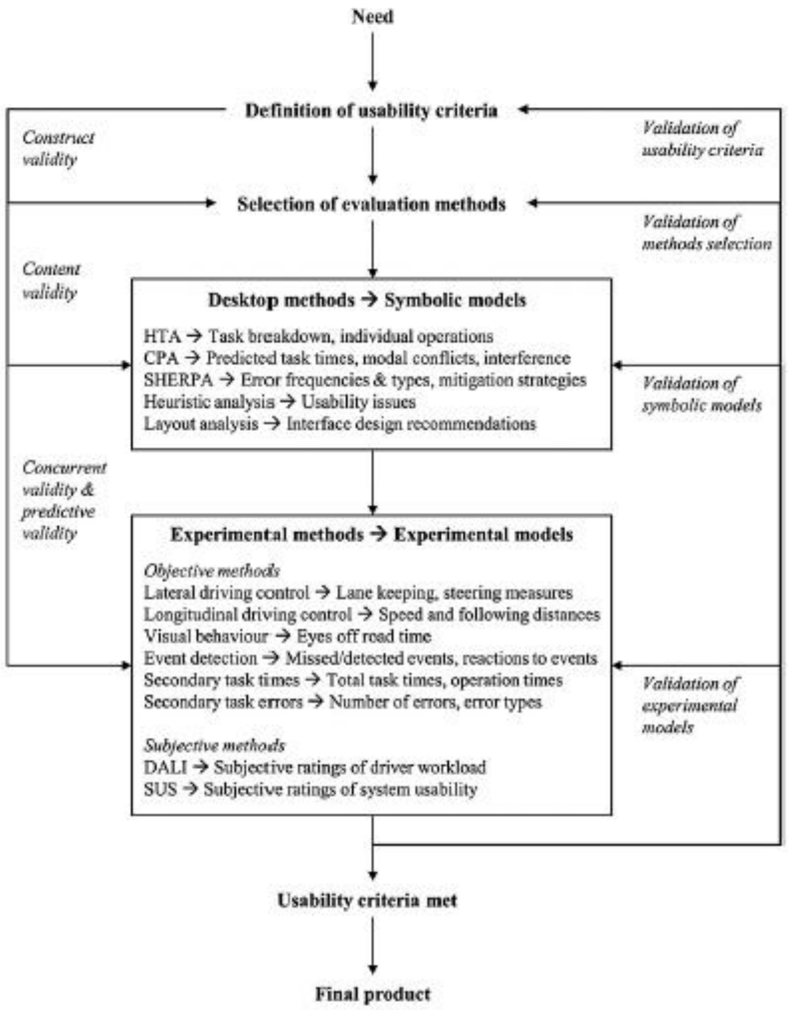

Figure 30: IVIS Usability evaluation framework by Harvey et al. (2011) *Applied Ergonomics 42 (2011) 571.*

Harvey et al. also lists four types of validity for the chosen evaluation methodologies; Construct validity, content validity, predictive and concurrent validity. These are determined by the appropriateness of the methodologies to the listed usability criteria, results of evaluations and comparing the results obtained from the methodologies respectively.

To choose appropriate evaluation methods for this project, the four principles listed by Harvey et al. were briefly described in accordance with the needs of the project.

Type of information required

The plan was to gather as many user inputs as possible for iterating the existing design. At the same time understand driver behaviour for the scenarios listed. A mixture of both objective and subjective data could be used to reflect on the effectiveness of the interface.

Stage of application

Since the design process is iterative, evaluation could take place throughout the design process. An icon intuitiveness test and evaluations through paper and desktop prototypes was already performed prior to readying the demo design for simulator tests.

Resources available

A desktop based simulator was available for conducting user tests. With these, data could easily be collected in a relatively short time. A real road study was not feasible even though they provide realistic road conditions.

People involved in evaluations

As indicated by Harvey et al., age and experience are considered two of the most important user characteristics in driving. These are to be considered while choosing a representative sample for evaluation. The sample considered in this study was a group of experienced drivers who had an annual driving distance of at least 15000 km. The representative sample was chosen after discussion with experts.

Three usability evaluation methods were chosen based on these guidelines for performing usability tests in the simulator: Heuristic evaluation, In-depth interviews and an Event detection tool-kit.

Heuristic Evaluation

A *heuristic* is simply defined as the characteristic of a good (or bad) user interface, based on the experience of an expert usability professional (Judy 2013). According to Nielsen & Molich (1990: P.249), 'heuristic evaluation is an informal method of usability analysis where an interface design is reviewed based on the comments of evaluators.' 'It is an analysis where experts judge aspects of a system according to a checklist of principles' (Harvey et al. 2011: P.568).

Advantages are that it is cheap, intuitive and easy to motivate people to do it, does not require advance planning, can be used early in the development process. Disadvantage is that results of these evaluations do not suggest how the problem could be solved. The method is prone to bias by the mind-set of evaluators and normally does not generate any breakthroughs in designs (Nielsen & Molich 1990).

A heuristic analysis was conducted in this project based on the usability principles proposed by Nielsen (1995a). The procedure for carrying out this analysis was adapted from that suggested by Judy (2013)**.** Visibility of system status, Match between system and the real world, Recognition rather than recall, Consistency and standards, Error prevention, Help users diagnose and recover from errors, Aesthetic and minimalist design and Help and documentation were the heuristics listed. In the next step, questions were framed with regard to each heuristic. The questions had multiple choices with a mix of rating scales and listed answers (see Appendix 18). The results for each question were visualized for analysis.

In-depth interviews

In-depth interviews were also used as an evaluation tool. According to Boyce & Neale (2006: p.3), 'an in-depth interview is a qualitative research technique to explore an individual's view on a particular idea, program, or situation.' The advantage is that these interviews provide much detailed information than what could be available through other data collection methods. Boyce & Neale (2006) also suggest that people feel more comfortable having a one-one conversation due to a much relaxed atmosphere.

Event Detection

Event detection is a method to record the driver's ability to detect and respond to events in the driving environment. It can be measured via the number of missed events compared to detected events, the number of incorrect responses to events, the response time and reaction distance (Young, Regan & Lee, 2009 as cited in Harvey et al. (2011)). In short, it is a measure of interference from secondary tasks in a driving environment. This evaluation tool is used late in the design process when access to a full prototype is possible (Young, Reegan & Lee, 2009 as cited in Harvey et al. (2011)). In this project, since no secondary tasks were included in the driving scenarios, the idea was to use a modified version of the tool-kit where events specific to the driving scenarios and design are considered (see Appendix 16).

The complete selection procedure with the chosen evaluation methodologies is summed up in figure 31.

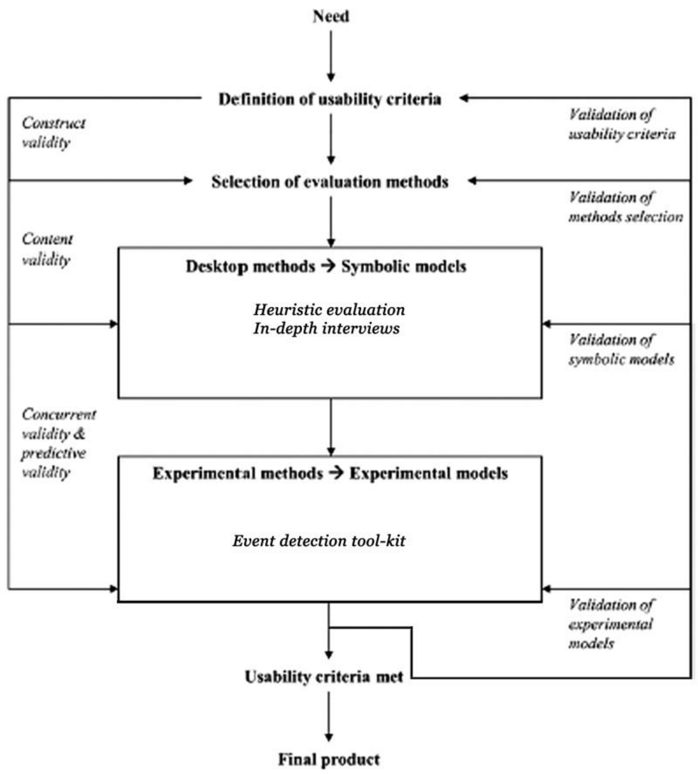

Figure 31: Usability evaluation framework with chosen evaluation methodologies in the project.

Participants

Participants were recruited through advertisements on the VTI website and posters placed at Chalmers University of Technology. In total 12 participants, 6 male and 6 female participants completed the experiment. The participants were between the age of 25 and 51 years (M = 31.83, SD = 7.95) who held a valid driver's license for at least five years. The annual driving distance covered by majority of participants was between 15000 and 20000 kilometres. The participants received a cinema ticket as a reward for their participation.

Simulator equipment

Simulators vary in sophistication and cost. These are available as single screen simulators, PC-based instruments, to high-end graphics, widescreen, fixed-base and moving base simulators (Santos et al. 2005). Simulator studies have several advantages in transport research. As indicated by Stanton et al. (1997), these can be used for testing users in conditions which may not be ethical if done in a real traffic environment.

This project uses the ITERATE desktop simulator located at VTI (The Swedish National Road and Transport Research Institute) (see figure 32). The simulator has been setup at VTI as a part of the European project ‘ITERATE’ (IT for Error Remediation and Trapping Emergencies 2012) with an objective to develop and validate a unified model of driver behaviour and driver interaction with innovative technologies in emergency situations. The purpose of using a unified model is to open possibilities for designers to identify potential problem areas at the prototype stage of development making it easier to adapt the system to the drivers before being available on the market.

Figure 32: ITERATE simulator at VTI (The Swedish National Road and Transport Research Institute)

More about the simulator hardware can be found in Appendix 1. The simulator uses a 3D graphics simulation package VISIR (Visual Simulation of Road/Rail) designed by VTI for research and training purposes. The package is built on OpenSceneGraph (OSG) graphical engine version 2.8.3 (www.openscenegraph.org) and the boost library 1.35.0 (www.boost.org). All code is written in C++ using Visual Studio 2008 for Windows and GCC for Linux.

The maximum speed was fixed at 70 km/h and the distance at 3.0 seconds time interval. The ACC system used in the simulator had certain limitations when compared to the commercial version. The driver could not accelerate or overtake manually once the ACC was activated. However, there was a possibility to switch ACC OFF by applying brakes. No manual buttons to turn ACC ON or OFF as in commercial ACC’s was included. Also, the gear and clutch functionality were disabled.

Experimental route and scenarios

A virtual representation of a Swedish rural highway with very moderate traffic was chosen. The driving environment resembled a clear summer day. Vehicles in the traffic were moving in the opposite direction to the simulator vehicle in regular intervals. The lead vehicle appeared on the road after an approximate drive of 150 seconds. The demo design was displayed on the extended screen (see figure 34). The ACC was activated when the driver accelerated to 70 km/h. Here an audio notification was conveyed to the participant. A distance of 3.0 seconds time interval to the lead vehicle was also pre-set. It was not possible to overtake the lead vehicle unless the driver applied brakes and switched to manual driving mode. The lead vehicle had a variable speed between 35 and 70 km/h during the car-following situation.

The following scenarios were considered for the simulator experiment.

Table 5: Scenarios and ACC failures used

Scenario	Criticality	Description	Failure used
A	Critical without warning information	Lead vehicle brakes. No warning conveyed to the driver.	Complete braking failure. The simulator vehicle does not initiate any braking power at all.
B	Critical with warning information	Lead vehicle brakes. Warning conveyed to the driver.	Complete braking failure. The simulator vehicle does not initiate any braking power at all.
C	Non-Critical with warning information	Lead vehicle drives at 70 km/h.	Complete braking failure while on the move.

Note: Success criteria for scenarios A and B are that the crash is avoided. In case of B and C the criteria is to see whether the warning is conveyed according to the driver's understanding. Whether the decisions made during the failure were supported by the warning.

The lead vehicle braked several times during the car-following situation. The failure was injected during one of those times. For instance, in scenario A, the failure was injected when the lead vehicle braked for the third time, but injected the second time in scenario B. This was to avoid consistent events in two consecutive scenarios. The warnings (both audio and visual) were conveyed to the participant in scenarios B and C. In addition to the three scenarios listed, a training scenario was also run for the driver to familiarize driving in the simulator. The training scenario spanned for 240 seconds and was run prior to running the above scenarios.

Experimental design

Each participant drove three scenarios in total excluding the training scenario. However, the order in which the participants drove these scenarios was different. As shown in the Table 6, the orders were counterbalanced so that there were two participants going through each of the six orders to avoid any order effects in the experiment.

Table 6: Orders of scenario exposure

Order	Scenario	Scenario	Scenario
1	A	B	C
2	A	C	B
3	B	A	C
4	B	C	A
5	C	A	B
6	C	B	A

Procedure

The procedure followed was quite similar to the one used in the SHADES project. Initially, a pilot study involving six participants (all of them employees at VTI) was performed to test the simulator set-up, the scenarios and the evaluation tool-kit. A common suggestion received was to include a brief presentation of the design concept to the participants before running the driving scenarios. However it was acceptable not to reveal the warning function in the interface. This was considered in the procedure. In the evaluation tool-kit, the heuristic evaluation questionnaire needed some modifications. Also, it was decided not to move forward with the event detection tool-kit due to the difficulty in recording the outcome of each of the events separately during a scenario. The decision to use a video camera to record the driving scenarios was also reconsidered as the setup became more complex.

On arrival the participants were given a brief introduction regarding the experiment and the functionality of ACC. Thereafter, the participants were given an informed consent form (see Appendix 13) which made it clear that they had the freedom to withdraw from the experiment at any point without stating any reasons. Along with this, the participants also answered questions about their background information (see Appendix 14). Before starting the scenarios they were also given a brief introduction about the interface as a printed paper prototype.

Initially, the participants drove a training scenario where they were briefed about the simulator functionality limitations such as the lack of gear shift functions, clutch and other secondary task functions from the steering wheel. Next, the participants drove the experimental scenarios in predetermined order (see Table 6).

After the completion of all the scenarios, an in-depth interview was performed to understand the participant's initial thoughts on what they experienced in the simulator, thoughts on driving with the warning information and without it, whether they preferred to add or remove any design elements from the interface and lastly thoughts on the existing audio notifications. The interview guide can be found in Appendix 16.

After the interview a heuristic evaluation of the interface was performed with the participants. In the end, the participants received a movie ticket for their participation in the study.

Data collection and analysis

The introductory session, the driving scenarios and the in-depth interviews were all compiled as an audio recording for analysis. Steering and braking responses were also gathered to understand driver behaviour during the scenarios. The data collection focussed on understanding the driver's perspective of the warning function. Continuous notes were also taken while running the scenarios to know whether the warning information conveyed in the interface during the failure was correctly interpreted by the participants. A probe on whether they understood the information presented in the interface was done during in-depth interviews and using the heuristic evaluation questionnaire. Scenario A and B was considered handled if the driver avoided the crash. In scenario B the failure was considered contained if the participant interpreted it was a failure in the ACC and switched it off by applying brakes. Scenario C was considered handled if the driver interpreted the warning correctly and switched ACC off before continuing the drive.

The analysis of the audio recordings were performed by listing different design features such as audio notifications, alerting texts, symbols and the heuristic principles and noting the comments related to these from recordings. The analysis of the heuristic evaluation questionnaire was also performed similarly. With this it was easier to identify which design feature or heuristic principle needed more attention for further iterations.

4. Results and Final design

4.1 Scenario A. Complete braking failure with no warning

In Scenario A, participants applied different responses to the failure condition, such as braking when the failure was injected and a combination of both steering and braking. Out of the 12 participants, 6 applied a braking response, handled the scenario and avoided crash. Those who preferred a combination of steering and braking did not handle the scenario and crashed into the lead vehicle as their responses were too late. 2 participants continued their drive without applying any response and crashed into the lead vehicle. One of them explained that he/she was waiting for a warning and another participant said he/she trusted the system too much.

Table 7: Scenario A. Complete braking failure with no warning

Response	N	Crashed	Handled scenario
Braking	9	3	6
Steering	0	0	0
Combination of steering and braking	1	1	0
Continued Driving	2	2	0
Total	12	6	6

4.2 Scenario B. Complete braking failure with the warning function

In Scenario B all the participants applied a braking response to the warning and handled the scenario. However, not all the responses were due to the combination of both the modalities used in the warning function or due to the warning itself. Majority of the participants used the audio warning as a cue to execute braking as a response. Only 4 participants interpreted the situation through the audio warning and the information displayed on the screen. Of these only 1 participant read the complete message on the screen and interpreted that ACC had failed.

Table 8: Scenario B. Complete braking failure with warning

Response	N	Crashed	Warning interpreted correctly	Handled scenario	Contained failure
Braking	12	0	1	12	4
Steering	-	-		-	
Combination of steering and braking	-	-		-	
Total	12	0	1	12	4

The participant explained:

> *"The sound made me look at the screen. I noticed the sound before I noticed the red thing on the screen. Then I read ACC FAILURE BRAKE and then I noticed the car in front of me was closing in and that's the reason I braked."*

Others read the message partly. One of them explained: *"I heard the sound and it said BRAKE, so I responded*." 2 participants insisted that their initial response was due to the car in front of them braking and that they saw the braking lights and their car getting too close to the lead vehicle. *"Good thing that the braking lights came on as well because the light actually made me realize there was something wrong going on before I heard the warning."*

Another participant who did not interpret the visual warning explained: *"I did not really see what the message was. When you are driving there is not time to read the message. So it should be your instinct to brake when you hear the warning sound."* One of them explained: *"I wanted to make sure the system was working, so I looked at the display, at least when I got closer to the car."*

Another participant described his/her experience as follows: *"When I had this warning, I heard the sound but I did not know what it was. So I had to watch the dashboard to understand that it was the ACC. But after that I was biased."*

4.3 Scenario C. Complete braking failure while both cars in motion

Scenario C involved a non-critical situation. 6 participants applied brakes when the warning was conveyed. However, only 4 participants interpreted the warning conveyed to them correctly. 5 participants continued driving after the warning was conveyed and 1 of them interpreted the warning information correctly.

Table 9: Scenario C. Complete braking failure while both the cars were in motion.

Response	N	Warning interpreted correctly	Handled scenario
Braking	6	4	4
Continued driving	5	1	1
Total	11	5	5

Note: One of the participants braked prior to injection of failure in the scenario and thus the scenario had to be discontinued.

The participant who read the message during the warning situation explained: *"The regular cruise control is still on but the braking function probably doesn't work, so I will have to be more careful now."*

Another participant who continued driving explained:

> *"I would've preferred if you would've shut off the cruise control all in all instead. Because now it was keeping the same speed /... / It was telling me it was failing and it did not do anything about it itself so if it notices it fails then it should just turn off. The message was clear when I looked at it even though it gave me a second off the traffic.*

If I would've seen it before, then I would've known what the message is and may be recognized the signal as well and then I wouldn't have had that delay."

One participant expressed his/her view on the text and audio warnings:

"There was too much text but in the first scenario (Scenario C) I read the text before doing anything because this was my first time. The sound made me to look into the display /... / The text on top was the first thing I saw. I felt there was something new there. I think the text should be as short as possible. I used the sound as the initial warning and the info on the screen."

Another participant suggested that the sound made him/her look into the display: *"The sound and I saw the red lights made me look into the display. I read ACC MALFUNCTION /... / I noticed that something is wrong with the help of warning sound."*

A few participants had opinions on the ACC technology itself. One of them stated:

"I wonder what will happen in a safety way in a highway driving if you push the brake and if there is another car behind. I like the technology but in some cases you can't rely on technology that much with that kind of speed."

4.4 On design

The following are a few comments and suggestions from the participants during in-depth interviews.

4.4.1 On Audio notifications

A majority of them did not recall the notification provided when the ACC was activated, but did recall the audio warning during the failure situation. One of them explained: *"The warning sound was comfortable. It doesn't really startle you or anything like that."* Another participant who did not recall the audio warning said: *"I did not notice the sound warning probably because my own car beeps all the time. It's always beeping."*

Another participant expressed his/her views on the warning sound: *"It was kind of simple. I don't know if I would want any other signal. Its sharp, it's not shocking and its regular ordinary car warning."*

Another participant explained:

"The sound was good. It was probably what I reacted on first. I heard the sound and then I saw something red that took over the dashboard main area." When asked whether they would prefer a warning without any sound one of them explained: *"No. Sound is more important to me because it draws attention."*

4.4.2 On alerting and informing texts

One of them explained about what type of information would he/she would like to be highlighted in the display during a failure:

"I guess I would want less 'BRAKE' there and bigger 'ACC MALFUNCTION' /... / When you are driving you may be the first car in a line of cars and then if it says

> *'BRAKE!' won't be good. If the car tells me something is wrong I want it to tell me and also to display what is wrong and not to assume what is the best course of action. May be brake is not the best solution at the moment depending on the situation. So I would like to decide about that myself."*

Few participants when asked about the text warnings expressed their discontent in not having enough time to read the complete warning from the display and felt that the texts were too long.

4.4.3 Symbols

When asked whether the symbols designed made any difference: *"Never saw any symbols. Those were too below."* Another participant explained*: "I did not pay attention to symbols or anything. I just paid attention on the speed and the warning signal."*

4.4.4 Colour coding

Majority of participants did not conceive the purpose of colour coding after the experiment even though the interface was explained prior to running the scenarios. However, a few participants expressed their views when asked about the different colour modes: *"I liked the one that it turned Red. That was the warning I noticed in the display."* Another participant explained: *"One thing that is good is that everything is kind of Blue normal and when something goes wrong it is Red and it really shows up because it's totally different colour and big contrast between red and existing colours."* When asked if they could differentiate between different modes the system was in, one of them stated: *"I liked the blue thing that showed the states."*

4.4.5 Optic flow patterns

There were several opinions on the particle system used in the display as an artificial optic flow pattern. One of them expressed his/her discomfort: *"I found a bit distracting with the white thing flowing because it was a movement."* Another participant stated that: *"It was a little bit distracting that is the reason I did not look at the display often."* One of the participants who preferred these patterns said: *"Even if you looked at something in the car you feel the speed. I would have that."* Another participant who conceived the purpose of these said: *"The white dots were showing the speed. I understood that, but it was distracting."* Another participant stated*: "I don't think the stars do that much good, even if it is a feedback for speed."* Most did not understand the purpose and felt it was distracting: *"I did not see the purpose of that star field."*

4.4.6 Re-design suggestions

Participants even had suggestions for re-design of the warning. One of them recommended:

> *"It is a self-explanatory interface /... / a shivering steering wheel would be possible. If you really want to warn somebody, either feedback on chair or steering wheel, but not pedals because you may not have your foot on the pedals always."*

Another participant expressed his/her desire to have the sounds louder. Few participants also had suggestions regarding alerting texts and the symbols. One of them said: *"Information symbols are so low. I would prefer them along the side. Have a white background and an alert text in red."* One of them had suggestions for using abbreviations instead of long texts: *"Reading the texts completely would be difficult. So maybe you could have abbreviations such as MAN for manual."* Another participant suggested: *"ACC FAILURE is enough as a message. That says everything."* One expressed his/her view on the placement of the text warning:

> *"Keep the text where you had it, because that is the first thing you see when you look down. Then again its sort of small area and if you got to have text, it should be big enough for everyone to read it. May be I would have a short text even if it is an acceleration problem or braking problem, I would just say ACC WARNING BRAKE."*

More general suggestions were also provided by the participants. One of them suggested: *"Make an X on ACC symbol that it's broken."* Another participant wanted a notification when a lead vehicle appeared in front. There were also views on the amount of information displayed. One of them stated that: *"I found too many sources of information that conveyed the same meaning."* Another participant expressed discontent in judging the distance to the lead vehicle: *"There is uncertainty because the 3 seconds, I don't know how far that is. So did not have a feeling for it as to when to brake."* Another view was regarding the learning curve for the interface. The participant explained: *"If you are driving little bit longer you get used to it and you know where to look at the interface when there is a warning."*

4.5 Heuristic Evaluation questionnaire

The results from the heuristic evaluation questionnaire are compiled in Appendix 17**.** This gave a better picture of what principle aspects of the interface needed improvement. Participants listed few more design suggestions for improving the warning. One of them wrote: *"There were multiple sources of information which conveyed that ACC was activated. You could take away the middle or left one."*

10 of the 12 participants indicated that they could differentiate between different modes. At the same time, 9 participants indicated they could clearly hear the warning sounds and were expecting a change in colour in the interface. This clearly indicates the preference for having an auditory modality to convey warnings. At the same time, also indicates the importance of using colour coding to convey system status to improve situation awareness.

Regarding the information density in the interface, 7 participants indicated the interface had a good information density. This suggests that the image schematic metaphors did have some impact on the participant's perception of the overall design. However, 7 participants did indicate that the text sizes were small and hard to read. This could mean that the metaphor for distributing information i.e. CENTER-PERIPHERY had an influence in the outcome whereas the BIG-SMALL metaphor for displaying texts needs to be further investigated.

When asked about whether they knew what had to be done when the failure was notified, 6 participants indicated that they knew they had to avoid the crash somehow and 5 of them indicated their choice was to apply brakes. This indicates that the warning information texts do need to be altered, which is indicated in the in-depth interviews as well.

When asked whether they could predict any outcome of the warning function in the interface even before the failure occurred. One of them stated that: *"Since it is a software interface I expected more information than a normal hardware dashboard. Ex: colour changes"*. One participant had commented on the design of the speedometer dial: *"The jagged parts on the speedometer above 70 km/h made me confused. I think colours would be enough to signal high speed or danger."*

A more detailed graphical compilation of results from the heuristic evaluation questionnaire can be found in Appendix 17.

4.6 Final Design

A final design is presented below considering the inputs from the study. Not all input could be considered but an attempt has been made to come up with the best possible re-design of the visual interface. The approach used to arrive at the final design needs a mention. Considering the design guidelines used to achieve an appropriate level of trust with the system which reduces the risk factors, it was important to pick the appropriate feedbacks from the user interviews and the heuristic study. For example, the change in colour modes supported conveyance of system status and did have an impact on the results. At the same time, the warning notification symbols had to be removed as it had little or no impact towards the warnings. The CENTER-PERIPHERY schema used had to remain. The texts used for conveying the warning had to be shortened for better interpretation of the situation.

Fig 50: Semi-autonomous drive mode

Fig 51: ACC Failure mode

Fig 52: Manual drive mode

5. Discussion

5.1 On methodology and realization

Before commencing the work on choosing the right methodologies to develop this concept, a thorough literature review was done. This was quite time consuming as it was a new topic of study and the findings from the study would pave way for making design decisions. The most difficult part was to choose from several requirements identified from the SHADES literature. It was hard to decide whether I had enough understanding of the topic before picking the requirements. And even after choosing the requirements to move forward with the project, it was again difficult to come up with enough references to make the right design decisions. Once the design guidelines and usability evaluation methodologies were chosen, I received feedbacks from the mentors during the mid-term evaluation on how to move forward with the usability tests which was very helpful as it saved a lot of time. The research phase ended at this stage and I had enough ideas to move forward with the design phase and usability tests.

One thing I would like to highlight is that at this stage I had given little importance on listing the software requirements of the simulator. This made me change the tools for programming the interface for the simulator several times during the project. The design phase could have been performed in a more effective way had I noted down the simulator requirements correctly in the early stages and by developing the prototype in *Processing* itself in the first place.

The design decisions and the choice of methodologies used could be debated. The decision to implement the warning function within the instrument display did not have many supporting references. The decision was made on the fact that real-time status regarding speed and vehicle warnings are displayed on the secondary task area. Hence the integration of visual warning for conveying ACC failures could be ideal in this area. For an automation failure affecting the lateral or longitudinal control of vehicle that gives the driver a very short duration of time to react (critical situation), a design concept implemented in the primary task area (the windshield) could have been ideal since the driver’s visual attention on the road is not hampered.

A few thoughts on the methodologies used for guiding the design and evaluation phase needs a mention. Methodologies such as choice of design direction and mood board did not provide enough inputs to the warning design as such. However, they paved the way to brainstorm ideas for sketching concepts for the instrument display where the warning could be integrated. It could be argued that had the focus been on designing the warning function and not on integrating it with the instrument display, a better result could have been achieved in terms of the warning function itself which was more important for the purpose of the project. This process of integrating both instrument design and the warning function consumed a lot of time in the design phase. Another methodology whose contribution to the project is minimal was the icon intuitiveness test. It was very interesting to design symbols for the interface and evaluate it with users. However, the results from the surveys indicated that the meaning I tried to convey with these symbols was hardly interpreted by the users. This problem could be linked with the design of the overall test methodology. The type of measures and criteria used could be debated. The reliability of the results could have been improved with an altered intuitiveness test. A more structured approach could have been followed by using visual representations of the symbols, one section representing cues and the other representing feedback that could be associated with these cues. Once this is set, a visual preference test or an association test could be conducted. In an association test a wider set of symbols could be shown where the subject is asked to associate these with an operation. In a preference test, the subjects could be asked to pick the representations that they think exhorts to the operation in the best and worst way. In addition to this, suggestions of representations could also be asked. The test could have yielded better results had it been performed during the interviews.

Even though the process of sketching concepts and coming up with new ideas is fun, doing it alone can be hard when you have to make key decisions during the work. There is always the risk of ‘egocentric intuition fallacy’ as suggested by Landauer (1997 cited in Harvey et al. 2011) which makes designers believe that their perception of a system is applicable to everyone else. This could be related to the choice made regarding the usability evaluation methodologies too. Also, the evaluation validity, i.e., Construct, content, predictive and concurrent validities for the methodologies chosen have to be clearly determined to know if the choice of selection was right.

Another thought is on the design guideline used; the concept of using image schemas to integrate user’s mental models in visual design. This was an interesting direction I chose in the project based on the findings from the SHADES study. But one must note that the only supporting reference I had where the design decisions were based on image schemas was from the software industry. The IBIS method referred to in the project was developed with a focus on software applications. The methodology developed was to derive design solutions that fit the mental models of the users by integrating image schemas into requirements. The authors indicated that this would lead to software applications that are intuitive to use. It was hard to find any related research in the automotive industry where interfaces or warning functions were developed using similar guidelines.

5.2 On results

The results indicate that majority of participants in all three scenarios preferred use of brakes to avoid a crash and thus handling the scenario. However, it cannot be concluded that this response was a result of identifying the failure. Also, it is rather hard to estimate to what extent the interface helped participants who did identify the failure and initiated a response accordingly. It is clear from the results that audio warnings played a key role in the participants’ decision to brake and handle a scenario. Few participants insisted that the audio warnings drew their attention on to the display where they were trying to interpret the situation better. This could mean that auditory modalities have a good influence in seeking a driver’s attention during automation failures.

In scenario B, a majority of participants who handled the scenario, associated their braking responses either to the audio warning or the braking lights from the lead vehicle with their car getting too near to it. This indicates the ineffectiveness of the visual warning implemented in the display in critical situations when the driver has very little time to interpret the type of failure. Few participants also insisted that there was hardly any time to shift their attention to the interface and identify the type of failure. However, those who did manage to have a second off the road during the failure interpreted the failure correctly. Although they did not manage to read the messages completely (as explained in the interviews), the participants understood there was a problem with the ACC.

The results from scenarios B and C indicate that few participants interpreted the warning information correctly. However, to what extent this inference is credible could be debated as these results are inferred solely with the supporting notes from observing the participants during the experimental scenarios and the audio recordings during the in-depth interviews and the scenarios itself. Again, considering the results from the interviews, participants could have been biased even though probing was used during the interviews. I feel that the credibility could have been improved had I used video recordings and eye tracking measures during the scenarios. These would also have influenced the choice of evaluation methodologies. At the same time, considering the fidelity of the simulator used in the project, these infrastructures may not have been possible.

In scenario C, which was a non-critical situation, the participants had enough time to interpret the situation. However, I realized during the experiments that there was a flaw in the way the design was presented. Here, once the failure is injected the audio notifications are conveyed and at the same time alerting and informing texts are displayed in the instrument design. These texts disappear and display changes to manual mode once the driver applies brakes. So, if the brakes are applied just by listening to the audio warning and not glancing into the display as well, alerting texts would not be present the next time the driver looks at the interface. However, the display still shows that they are in manual driving mode and that the ACC has been switched off. The participants who applied brakes because of the audio warning and then looked at the interface insisted that the message on the screen disappeared when they were about to read it. So they could not interpret the exact failure although they knew they were in manual drive mode and ACC was switched off. This indicates it was preferable to leave the alerting texts for a longer duration even after the driver applied the brakes. But at the same time, had the driver applied brakes after reading the alerting texts and the texts stayed for a longer duration, this would be a flaw too.

A thought on the validity of the results needs a mention. The simulator used in the project is a static desktop simulator and hence the validity of the results obtained from the tests could vary if similar tests are performed in a moving base simulator.

6. Conclusion

6.1 General conclusions

Mode based design is the right direction for automated systems as these not only help in conveying the different mode the driver is in, but also act as a warning function due to apparent changes in modes which the driver can recognise.

Use of auditory modality is a must when it comes to designing warning interfaces. They help in attracting driver attention when the visual modality is occupied. The audio warning used for evaluation was ideal for drawing driver attention.

Allocating visual information regarding system status of automated functions in the instrument display is not recommended at least while considering critical situations where even a second off the road could prove to be fatal for the drivers. However, for non-critical situations, it is feasible to present the warning information in the secondary task area as long as an additional auditory warning is included. Use of colour coding for conveying visual warning was ideal.

Simulator based iterative design methodology is a very economic approach to use when it comes to designing prototypes for early usability tests. With usability tests being performed throughout the SBD process, it is much easier to refine the concepts when it approaches the final stages of development. Also, the possibility to test alternate concepts in the simulator in shorter times makes the process rather an easy methodology to adapt for the evaluators. However, conducting usability studies in driving simulators is still a challenge as the results are open to bias and is influenced by the representative sample.

In-depth interviews in combination with audio recordings were very productive as it gave an opportunity to probe more about the design with the participants. The participants were very comfortable answering questions regarding the scenarios as it was a one-one interview.

Heuristic evaluation provided a more detailed presentation of the design problems identified by the participants. This helped in listing more design suggestions for future work.

With the evaluation methodology used, it is still unclear whether the design has supported the driver in achieving a calibrated trust. However, it could be noted from the studies that the use of image schematic metaphors did provide some support in conveying different modes of ACC. Specifically, the colour coding and the audio warnings. Measuring the level of appropriateness of a user’s mental model is a challenge and only subjective measurements is used to support the results in this study and these are open to interpretation and opinions. With continuous exposure to the system, the participants may develop an appropriate mental model.

6.2 Answers to research questions

How should the interface of an adaptive cruise control system be designed in order to support transition between different modes in the system?

Presentation of continuous information regarding automation is a must as the driver needs to be informed about the status of the system to avoid any criticalities regardless of the mode they are operating in. With this work, it is rather unclear to what extent the evaluation methodologies and design decisions have contributed to designing an HMI for conveying technical failures in ADAS's. User centred design may not be the right approach to take for designing interfaces that convey real-time status of a system.

It is also a thought that the research question could have been altered a little during the work to make the purpose a bit clearer in the beginning. The transition between different modes could be achieved if the limits of ACC are addressed. Had the approach been to design an HMI to make the ACC limits visible for the driver, it could have had a better outcome in terms of driver understanding of the technology and the results from the study.

How can failures in the adaptive cruise control system be notified so that the drivers make the right decision under different driving scenarios?

Multimodal displays will play an important role in conveying automation failures depending on the criticality of failure. All the visual information regarding primary tasks that have direct interaction with the traffic such as longitudinal and lateral control of the vehicle are to be preferably displayed in the primary task area. However, considering the presentation of the warning function for notifying failures, these are also dependent on the criticality of failures. For less critical situations, presenting information within the secondary area can have positive outcomes.

6.3 Future recommendations

- The sound notifications need to be evaluated thoroughly in the future with advanced tools and methodologies.
- The interface does not have the capability to provide "hand-over" of control from the system other than when the failures occur. A possible addition of a button function which could help the driver switch modes is recommended.
- More tests in a moving base simulator are recommended for increasing the validity of results from the study and for further design iterations. A larger sample of participants could also be considered for future evaluations.
- Use of 3D sounds for notifying failures in a cockpit environment is an area to research on.
- Processing as an IDE and programming language for developing visual interfaces for similar research work is highly recommended as it is light-weight and easy to learn.

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Appendices

Appendix 1

Simulator hardware

The hardware that is used for the car simulator is as follows (see Figure 33):

- HPZ400 workstation running Windows 7. This generates the visual simulation imagery at 60Hz. It needs to be powerful enough to run all the components of the simulation.
- Samsung 40" wide-screen 1920x1080 monitor. This displays the main driver view.
- ViewSonic 15" wide-screen 1366x768 monitor. This displays the instrumentation for the dashboard, including any automated safety systems such as ISA (Intelligent Speed Adaptation).
- Logitech G27 steering wheel and pedals for the car. This is the market leader for low-cost steering solutions and we have experience with its predecessor, the G25.
- A GameRacer seat with mounting points for the wheel controller. This provides support for the driver for long periods and helps to avoid modifying an existing seat in a workshop with associated problems of design and manufacture. This is compatible with the controllers chosen and folds compactly for shipping or storage purposes.

Fig 33: Seat, Primary display stand and secondary monitor stand with shelf for car controller (Duncan n.d.).

Appendix 2

Computer Programs

The following section will give a brief introduction about the programs used in accomplishing this work.

Design Tools

Adobe Illustrator is vector based graphics editor marketed by Adobe Systems. A clear advantage working with vectors is that the object can be scaled to any dimension without losing quality. The program is used in a variety of design works such as creating web graphics, print designs and posters (Ar Connect n.d.).

http://iit.edu/arc/workshops/pdfs/illustrator_workshop-Jeff.pdf

Blend for Visual Studio is a tool developed by Microsoft® for building rich interactivity with vector graphics, animation, data binding, video and audio. It is a front-end development tool for designing XAML-based interfaces for both desktop and web applications (Panwar 2011).

http://www.c-sharpcorner.com/uploadfile/cd80b9/what-is-microsoft-expression-blend/

Programming tool

Processing is a programming language, development environment and online community. The IDE (Integrated Development Environment) is used for developing interactive programs with 2D, 3D or PDF output. It is normally used by new media art and visual design communities. The language builds on Java with a simplified syntax. The project was initiated in 2001 by Benjamin Fry and Casey Reas at the MIT Media Lab. It is free to download and open source. (Fry & Reas n.d.)

https://processing.org/

Sound effects

The sound effects used for the warnings and notifications were downloaded from a web resource for sounds freeSFX, UK (freeSFX n.d.).

Appendix 3

Design directions

The keywords used towards choosing a design direction for concept development is shown below. A mixture of both traditional and futuristic display design direction was chosen for the concept.

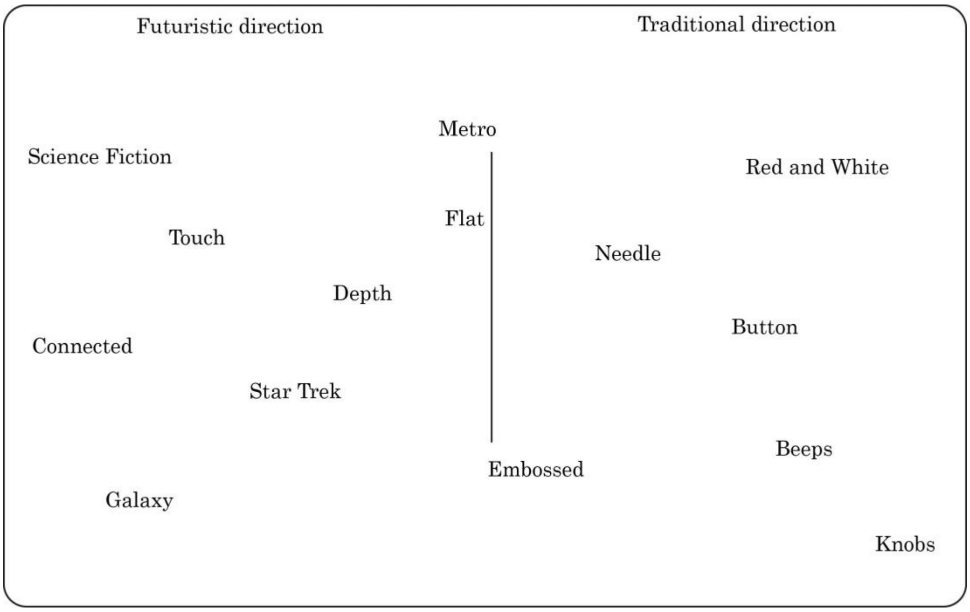


Fig 34: Populated keywords for design direction.

Appendix 4

Mood board

Fig 35: Mood board.

Images used from the following references:

(Stoneham Ford n.d.), (Bien n.d.), (Beissmann 2013), (BMW n.d.), (Chauhan 2013), (Daniel 2012), (Ayapana 2012), (Melanson 2009), (Naivi 2005)

Appendix 5

Sketches

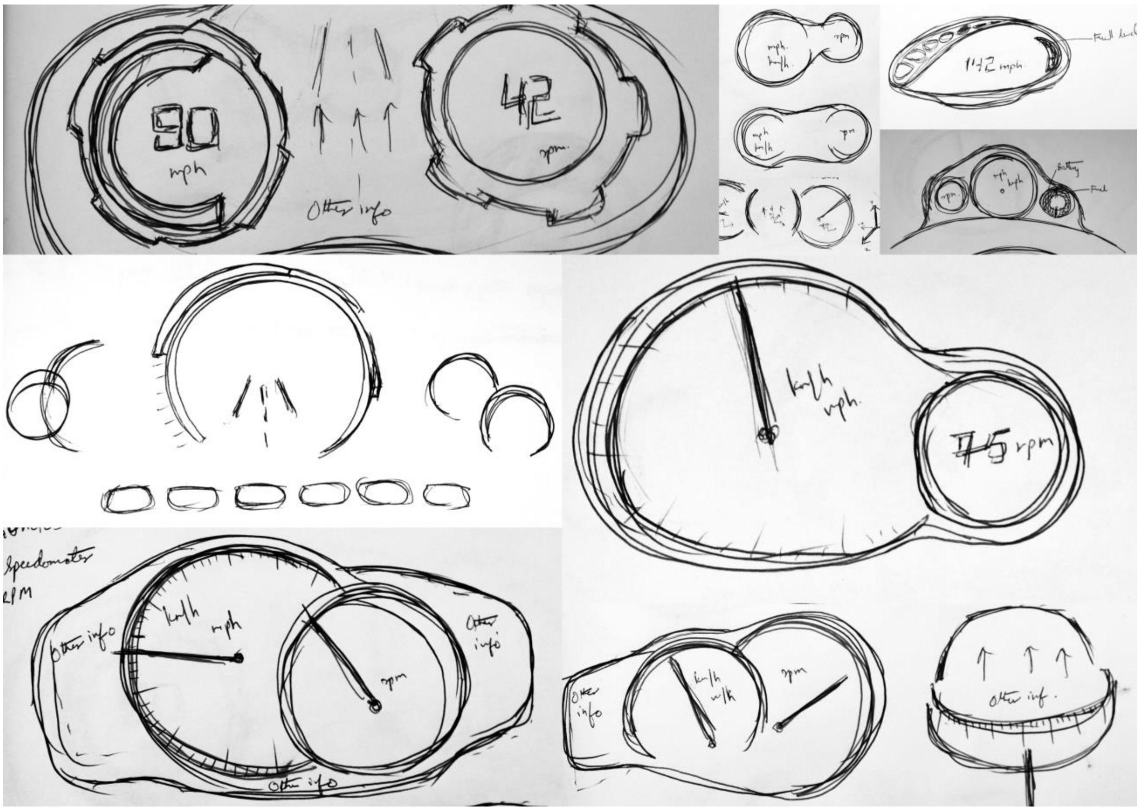


Fig 36: Concept sketching.

Appendix 6

Layout

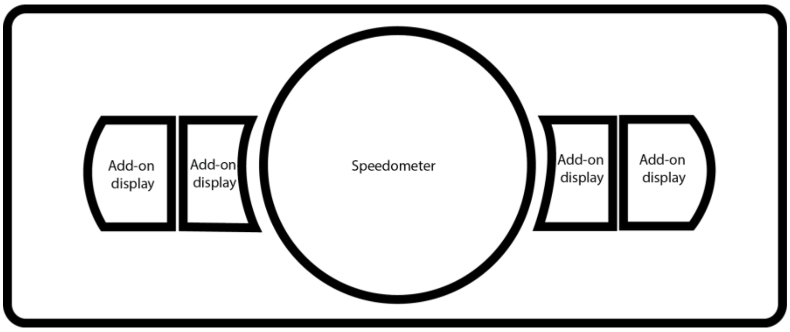


Fig 37: Layout 1.

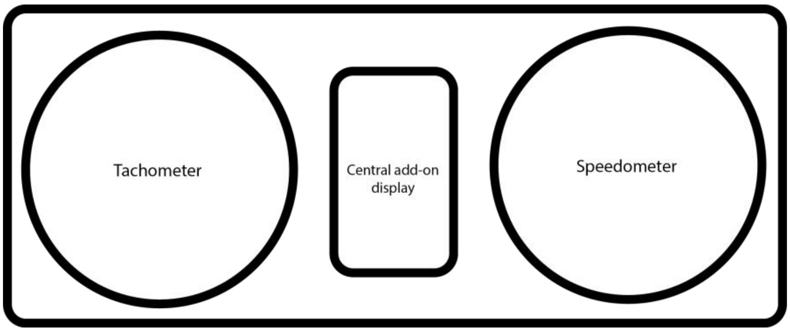


Fig 38: Layout 2.

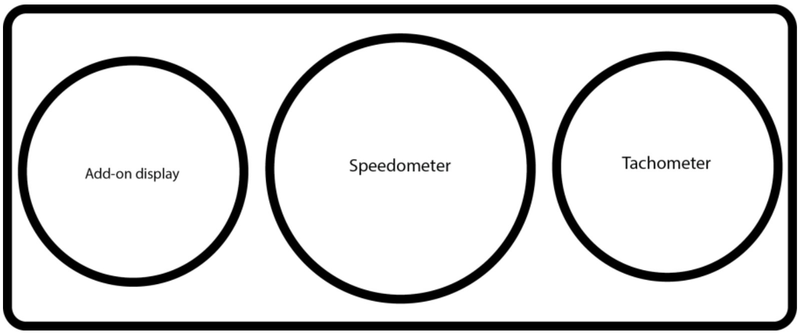


Fig 39: Layout 3.

Appendix 7

Emotion concept

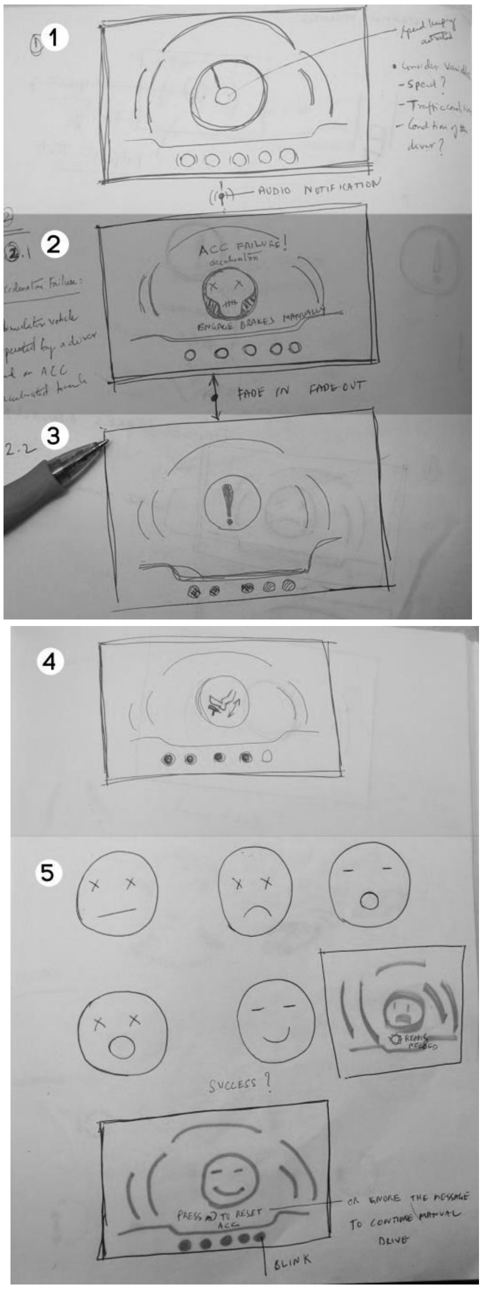


Fig 40: Emotion concept paper prototype.

Appendix 8

Desktop Concept

Paper prototypes

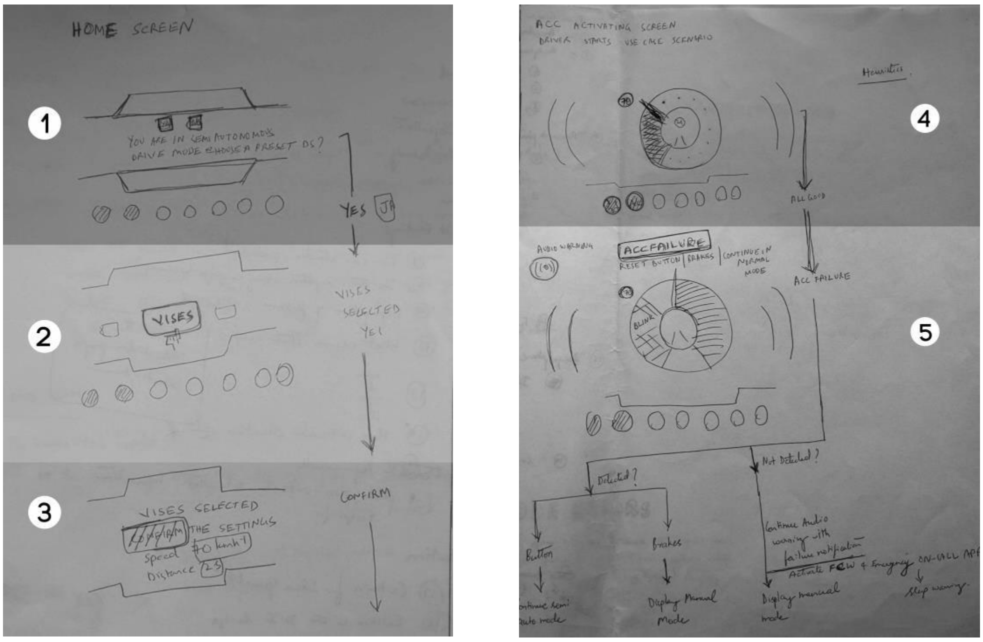


Fig 41: Paper prototypes.

Low-fidelity desktop prototype

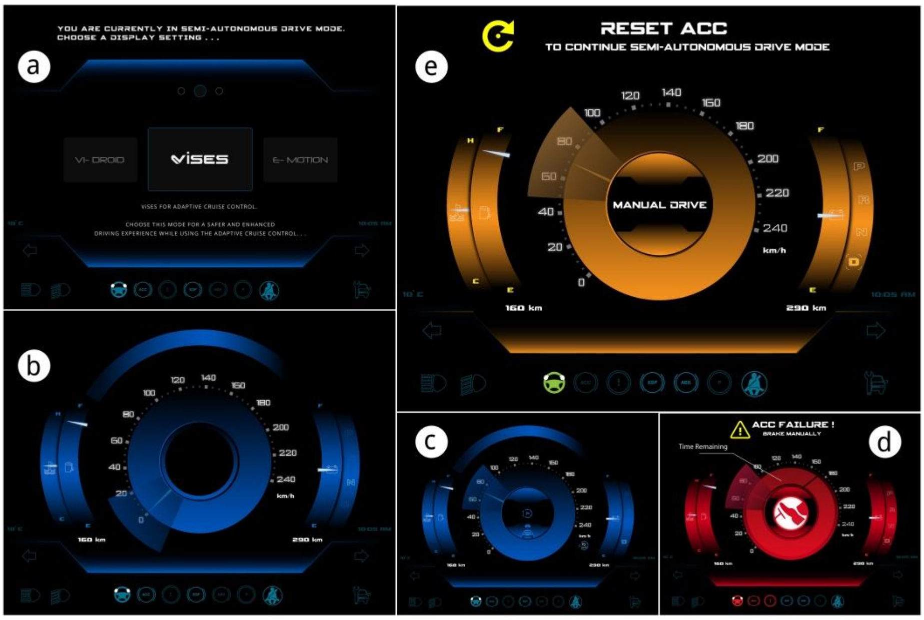


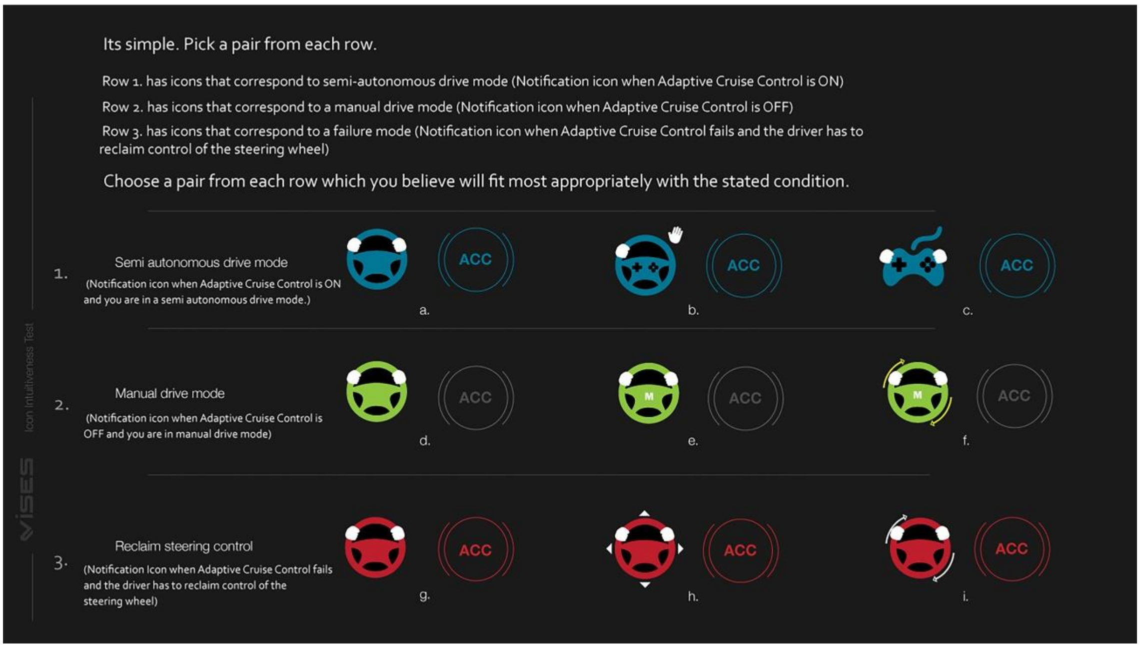
Fig 42: Desktop concepts.

Appendix 9

Icon intuitiveness test

Question 1

Choose a pair of symbols from each row which you believe will fit most appropriately with the stated condition. You are free to add additional comments and suggestions.



1. Semi autonomous drive mode

○ Pair a. ○ Pair b. ○ Pair c.

Additional comments

[ ]

2. Manual drive mode

○ Pair a. ○ Pair b. ○ Pair c.

Additional comments

[ ]

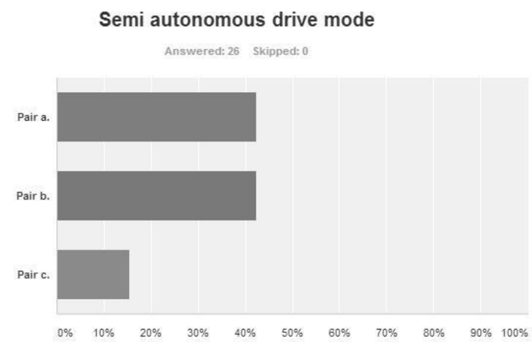
3. Reclaim steering control

○ Pair a. ○ Pair b. ○ Pair c.

Additional comments

[ ]

Survey Response



Answer Choices	Responses	
Pair a.	42.31%	11
Pair b.	42.31%	11
Pair c.	15.38%	4
Total		26

Comments

Showing 7 responses

I don't understand the gaming control, what does that have to do with it? What is the raised hand?
1/20/2014 6:43 PM View respondent's answers

Why the steering wheel symbol? Steering is not speed/cruising.
1/20/2014 5:49 PM View respondent's answers

Why a game control on C? I would wish to have the ACC icon in a thicker line, so it feels closer in importance to the steering wheel
1/20/2014 9:15 AM View respondent's answers

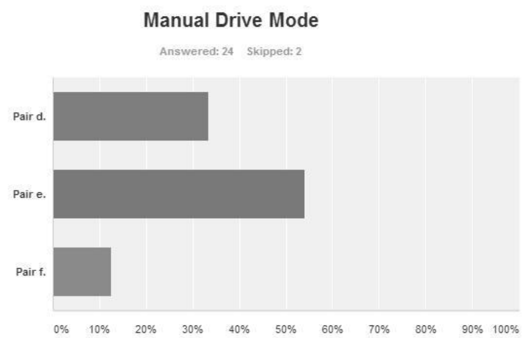
I think the colors should be green for autonomous drive, and blue for manual drive.
1/16/2014 9:37 AM View respondent's answers

Game control symbols in b not neccesary.
1/15/2014 8:27 AM View respondent's answers

What the controllers in the steering wheel for?
1/14/2014 5:37 PM View respondent's answers

Maybe steering could look same as pair a?

Survey Response



Answer Choices	Responses	
Pair d.	33.33%	8
Pair e.	54.17%	13
Pair f.	12.50%	3
Total		24

Comments

Showing 4 responses

I don't think any of them are clear enough. There should be more than colours differentiating the modes
1/20/2014 6:43 PM View respondent's answers

I don't think there should be a symbol for "normal" driving
1/20/2014 5:49 PM View respondent's answers

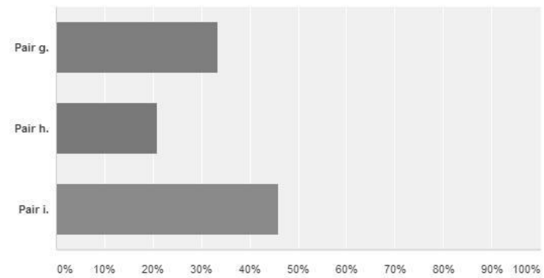
The white M in the bright green background does not read well, Would rather have it black
1/20/2014 9:15 AM View respondent's answers

I am not sure that the ACC icon should be visible at all during manual driving
1/15/2014 7:51 AM View respondent's answers

Survey Response

Reclaim steering control

Answered: 24 Skipped: 2



Answer Choices	Responses	
Pair g.	33.33%	8
Pair h.	20.83%	5
Pair i.	45.83%	11
Total		24

Comments

Showing 5 responses

I don't think any of them are clear enough
1/20/2014 6:43 PM View respondent's answers

Once again: Why the steering wheel symbol? Steering is not speed/cruising.
1/20/2014 5:49 PM View respondent's answers

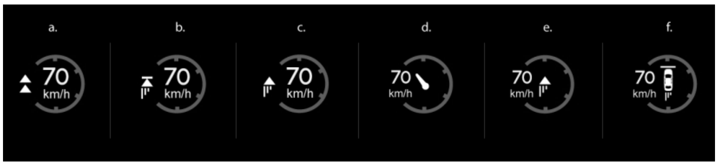
Pair g would be the most appropriate for me out of the three alternatives, however, I don't think it pair g is good enough.
1/20/2014 10:36 AM View respondent's answers

I would in some way cross off the ACC. Either turn it off and have the steering wheel flashing red, or a flashing cross over the ACC icon.
1/20/2014 9:15 AM View respondent's answers

Reclaiming control means normal driving, thus using the manual driving symbol again. The red color for urgency makes it work fine.
1/14/2014 5:37 PM View respondent's answers

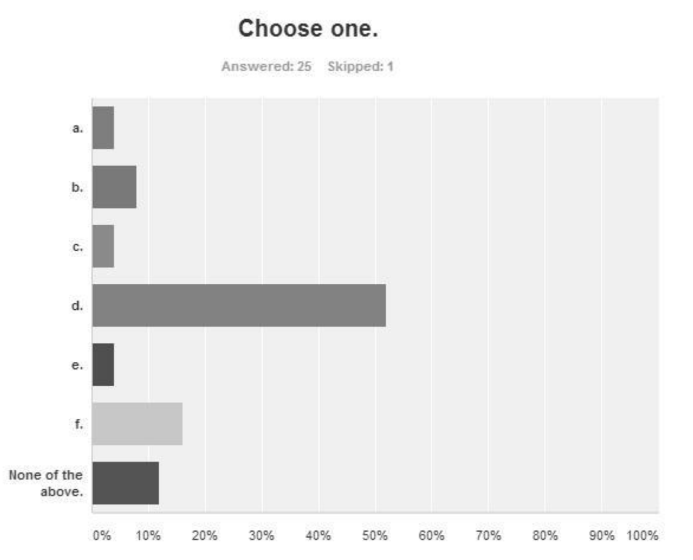
Question 2

Choose a symbol below that closely illustrates 'set speed is 70 km/h' in a vehicle fitted with Adaptive Cruise Control. You are free to add additional comments and suggestions.



4. Choose one. ○ a. ○ b. ○ c. ○ d. ○ e. ○ f. ○ None of the above.

Survey Response



Comments

Showing 5 responses

Looks now like it's only speed limit. Can the vehilce ahead be more clearly shown to really show that your car can follow the car's ahead speed?
1/20/2014 6:44 PM View respondent's answers

I associate a. with Fast forwarding, b. with Jump to next, c. with Play. I don't understand e., and f. looks like as it is ok to drive into a wall in 70km/h.
1/20/2014 5:57 PM View respondent's answers

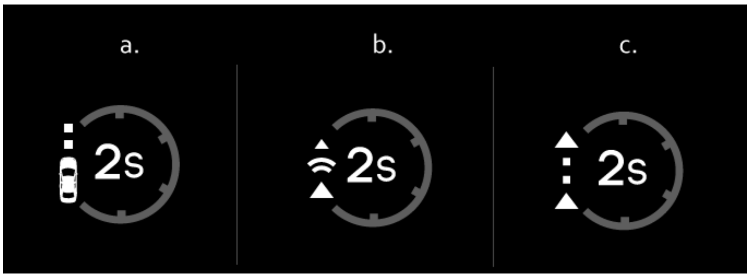
F is nice as well. I've chosen it first, but then I caught an idea that the picture reminds me a colission. :-)
1/17/2014 10:41 AM View respondent's answers

Do not like all the arrows next to the speed, implies movement. lock the speed the between parenthesis or something.
1/14/2014 5:47 PM View respondent's answers

need information that ACC is on
1/14/2014 4:47 PM View respondent's answers

Question 3

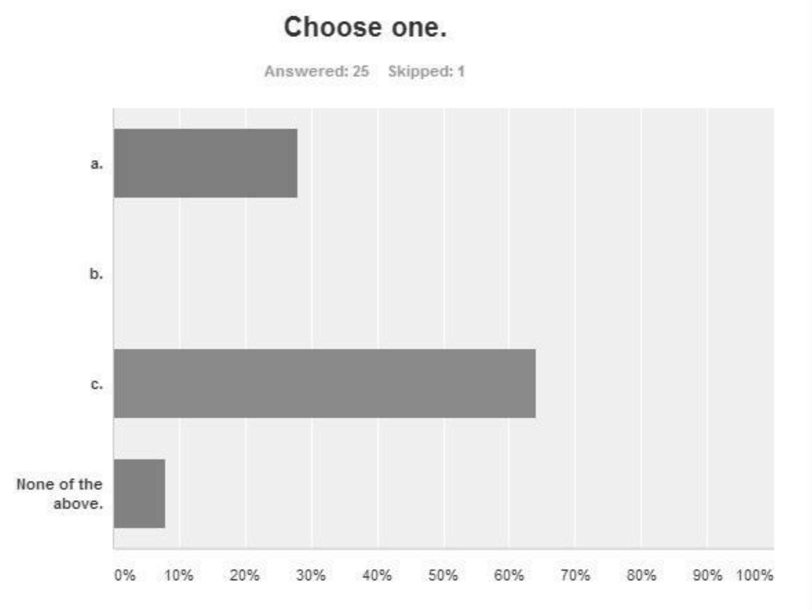
Choose a symbol below which closely illustrates 'set time interval is 2 seconds' in a vehicle fitted with Adaptive Cruise Control. You are free to add additional comments and suggestions.



5. Choose one.

- a.
- b.
- c.
- None of the above.

Survey Response



Comments

Showing 4 responses

I feel a limited need to set a time interval measured in exact seconds.
1/20/2014 5:57 PM View respondent's answers

Time interval to impact? I am not sure what this time interval is for... so I am a bit doubtfull about the icon as well.
1/20/2014 9:17 AM View respondent's answers

I could also consider having two cars in the icon with the dots between.
1/15/2014 7:54 AM View respondent's answers

need information that ACC is on
1/14/2014 4:47 PM View respondent's answers

Appendix 10

Simulator prototype

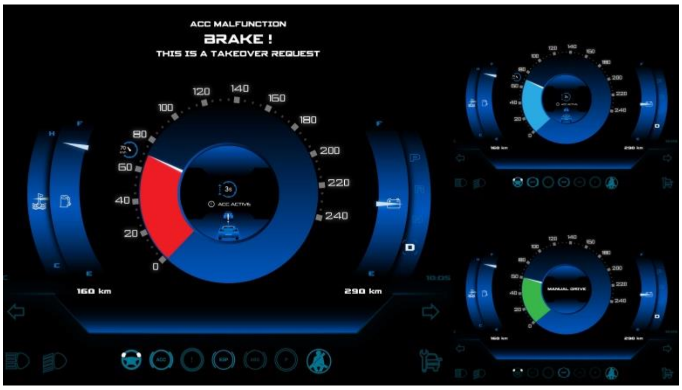


Fig 43: Clockwise from Left- ACC failure mode, ACC active/ Semi-autonomous drive mode, Manual drive mode.

Final simulator prototype

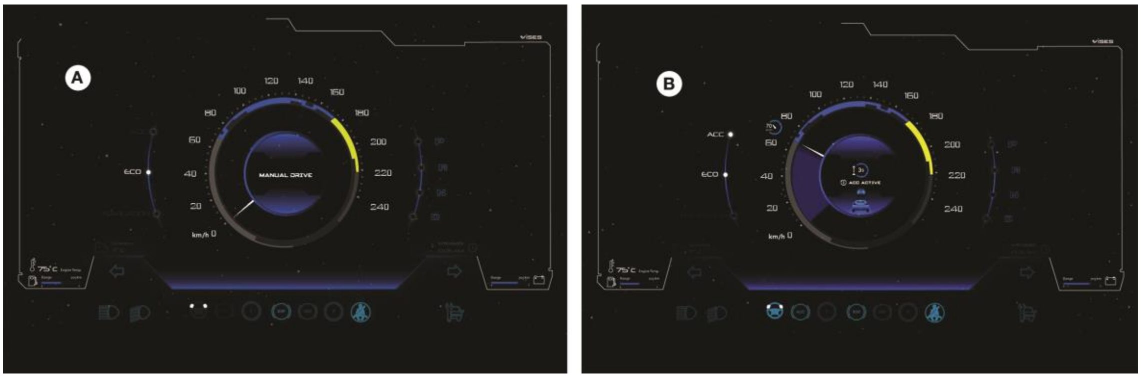


Fig 44: A- Manual drive mode, B- ACC Active mode

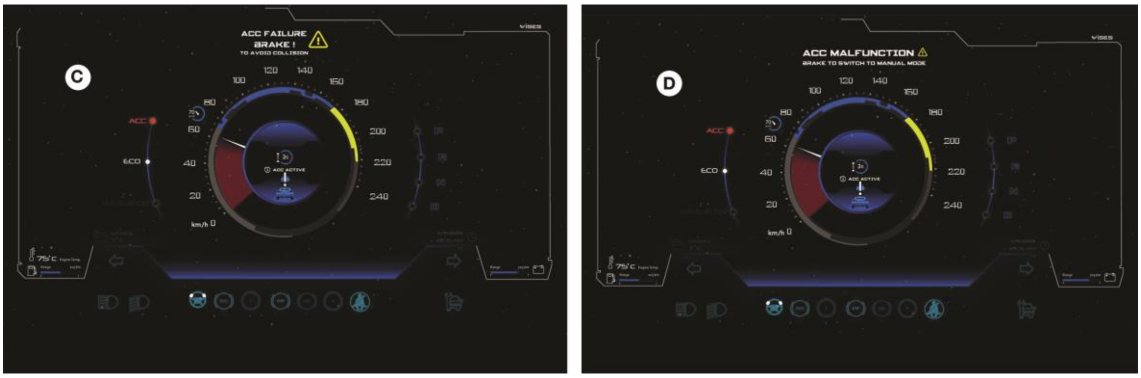


Fig 45: C- ACC failure mode when in critical situation. D- ACC failure mode when in non-critical situation.

Appendix 11

Code

The dashboard interface application code is written in *Processing* and is available at the following link:

https://github.com/kksreejith/Dashboardinterface

Appendix 12

Manuscript

Hai welcome to today's study. Do you love driving? Do you have a car?

1. **TELL THEM ABOUT THE ACC**

Ok great, do you know what an adaptive cruise control is? Have you heard of conventional cruise controls?

Adaptive cruise control is similar to conventional cruise control in that it **maintains the vehicle's pre-set speed**. However, unlike conventional cruise control, this new system can **automatically adjust speed in order to maintain a proper distance between vehicles in the same lane.**

Say you are about to drive a car and you would like to switch ON the ACC. You set the speed to say 70 km/h as in conventional cruise controls, but at the same time you set the distance or time gap to say 3seconds. This setting maintains a time gap of 3 sec between your car and the vehicle in front. If there is no vehicle, the system switches back to conventional cruise control mode and travels at the set speed, i.e. 70 km/h.

So that means, you don't have to use the gas pedal while the ACC is ON and your car is cruising at a set speed. You only need to steer your car in the right direction, which results in a more relaxed form of driving. It is more of a semi-autonomous mode of driving.

2. **TELL THEM ABOUT THE ACC FAILURES**

But there are situations when the ACC fails and the driver has to act accordingly. Say the ACC is switched ON and you are following a car ahead. Now, suddenly there is a failure in the ACC and you don't know what is happening and you just crash into the car ahead.

3. **TELL THEM ABOUT THE INTERFACE**

Show the screens and explain the interface. Don't explain the warning.

4. **TELL THEM ABOUT WHY YOU ARE DOING THE EXPERIMENT TODAY**

So what I have developed is an interface to convey these ACC failures to the driver and help them make the right decisions during these situations. So that is one reason why I am evaluating the interface. Another reason is to see if the driver can distinguish between different modes of ACC. That is the ACC active mode, manual drive mode and the failure mode.

1. **So here is the setup, you may take your seat. You will listen to the instructions first, and will only begin the drive when I ask you to.**

   So first you will drive a practice scenario where you can have an experience driving in a simulator.
   Then you will drive 3 experimental scenarios one by one.

Appendix 13

Information consent form

Thank you for choosing to come here today. I, Sreejith K K (Master's thesis worker at VTI, The Swedish National Road and Transport Research Institute/ Chalmers University of Technology) will be conducting the study today which is a part of my thesis work.

The simulator study will involve driving a car with driver assistance systems. In addition to driving in the driving simulator there will also be a short interview and a short survey to fill out. Estimated time for this is about 30-45min.

Participation in the study is voluntary and you can at any time choose to discontinue your participation without giving any reasons.

All information collected during the study from the simulator (log files, videos), questionnaires, and during the interview (audio recording's) will be treated confidentially.

The information from the simulator will be stored for 2-3 months. Audio recordings will be erased after this period. The recorded interview will also be stored for 3 months. Video material will not be stored without specific consent for this is given.

If you have questions or want more information, you can contact me for any additional information.

If you have read and understood the above as to what your participation in this study involves please give your consent to participate.

☐ Yes I have read and understood the above information about what my participation involves leaving my consent to participate in the study.

☐ In addition to the above, I also give consent for video footage which may be used in presentation and other seminars.

☐ No, I do not agree with any of the above.

Participant

Name: Date: 2014-Feb-

Signature:

Investigator

Name: Sreejith Kuppattu Kalladithodi Date: 2014-Feb-

Signature:

Appendix 14

Participant background information

Below are some questions I'd like you to answer. If anything is unclear, feel free to clarify.

Background Information

1. Gender: ☐ Male ☐ Female

2. Age:

3. How long have you been driving? . . . .years

4. Select the driving license/'s you hold

☐ A ☐ B ☐ C ☐ D ☐ BE ☐ CE ☐ DE

5. An estimation of annual driving distance in miles?

☐ 0 ☐ 1-500 ☐ 501-1000 ☐ 1001-1500 ☐ 1501-2000 ☐ 2001-2500 ☐ >2500

6. Are you passionate about in-vehicle interfaces?

   ☐Very much ☐Somewhat ☐No. Don't interest me.

7. How much do you trust the warning notifications in your car?

   ☐Very much ☐Somewhat ☐Don't trust them at all

8. Have you ever wished you had more reliable warning notification system in your car?

   ☐Always ☐Sometimes ☐No

9. Have you ever driven cars fitted with Adaptive cruise controls?

   ☐Yeah ☐Never ☐I don't know what that is

Appendix 15

Event detection tool-kit

Participants	Without Warning						With Warning					
	Event						Event					
	a	b	c	d	e	f.	a	b	c	d	e	f.
1.												
2.												
3.												
4.												
5.												
6.												

Event detection toolkit:

a. = Whether the audio notifications led the users to focus on the interface.
b. = Whether the icon and text notifications gave the users the right status of the system.
c. = Whether the particle system had any influence on users perception of current speed status.
d. = Whether the change in gradient colour helped them identify different modes the system was running in.
e. = Did the user respond accordingly to the warnings and contain the failure.
f. = Whether the user detected the failures even without the warning.

Appendix 16

Interview guide

Body:

1. Any initial thoughts about what you experienced in the simulator?
    Scenario A
    Scenario B
    Scenario C

2. How did you experience driving with the warning and without it?

3. What was the most interesting aspect of the interface you liked in connection with the ACC? Why were these aspects interesting?

4. What notifications can you recall?

5. What changes were you expecting in the interface when the ACC was activated and during the course of ACC failure?

    Sound…..Why was that important to you? Why did that matter to you most?

    Change in colour in the interface…..Why was that important to you? Why did that matter to you most?

6. What changes would you prefer to add or remove in terms of the warning notification that was conveyed?

7. If you were a designer how would you design a warning notification feature for ACC failures?

8. Anything more you would like to add?

Epilogue:

Please fill out the questionnaire

Thank you for participating

Appendix 17

Heuristic evaluation questionnaire and heuristic principles

Visibility of system status

1. Was the set speed limit **when the ACC was activated** clearly visible in the interface?
    A. Yes.
    B. Yes, but could be improved. (Please specify)
    C. Not visible at all
    D. I did not see any limits

Choice	**Total**
A	10 participants
B	2 participants
C	0 participants
D	0 participants

2. Were you able to differentiate between different modes in the interface? Manual Mode, ACC Active Mode and Failure Mode?
    A. Yes all of them
    B. Yes, but except . . . . .Mode/s
    C. I could not differentiate between any modes

Choice	**Total**
A	10 participants
B	0 participants
C	2 participants

3. Was the first sound notification audible enough to notify that the ACC had been activated?
    A. Yes, I could clearly hear it, and it was the right notification
    B. Yes, I could clearly hear it, but I'd prefer other sound notifications if I had a choice
    C. I heard some notification, but it was not audible enough to convey ACC was activated
    D. I did not hear any notifications when the ACC was activated

Choice	**Total**
A	9 participants
B	0 participants
C	2 participants
D	1 participant

4. Was the warning sound notification audible enough to notify that there was an ACC failure?
    A. Yes, I could clearly hear it, and it was the right notification
    B. Yes, I could clearly hear it, but I'd prefer other sound notifications if I had a choice
    C. I heard some notification, but it was not audible enough to convey ACC had failed
    D. I did not hear any warning notifications

Choice	**Total**
A	9 participants
B	0 participants
C	2 participants
D	1 participant

Match between the system and the real world

5. Were the text warnings clearly readable?
    A. Yes, I could clearly read all of them
    B. Yes, but a few were really small in size and hard to read
    C. Yes, but only those in the center of the interface

D. Yes, but only those in the top of the interface

E. No, I could not read any information

Choice	**Total**
A	1 participant
B	7 participants
C	0 participants
D	3 participants
E	1 participant

Consistency and standard

6. Were there too many sources of information that conveyed the same meaning for you? If yes, then please specify.

Error prevention

7. Did you understand you had to apply the brakes to revert the failure reported in the ACC?

   A. Yes, I heard the warning sound and saw the text warning and icon notifications and felt I had to apply the brakes.

   B. Yes, that was my instant reaction to the sound warning.

   C. Yes, that was my instant reaction to the change in color mode in the interface. (Blue to Red)

   D. Not at all, I dint know what to do.

Choice	**Total**
A	5 participants
B	2 participants
C	2 participants
D	2 participants

Recognition rather than recall

8. Was it possible to predict the outcome of the warning function in the interface even before the failure occurred?
   - A. Yes, I was expecting some notifications to change their properties. (Please specify)
     - a. Colors of Icons (if any). . . . .
   - B. Yes, I was expecting an audio warning during the ACC failure
   - C. No, I could not predict the outcome

Choice	**Total**
A	6 participants
B	3 participants
C	2 participants

Aesthetic and Minimalist design

9. Was there a good information density in the interface?
   - A. Yes, totally
   - B. Yes, but I would like to suggest some improvement (Please specify)
   - C. No, the information were poorly placed

Choice	**Total**
A	5 participants
B	7 participants
C	0 participants

10. How would you rate the distribution of warning notification icons in the design?
    - A. Extremely poor
    - B. Below average
    - C. Average

D. Above average

E. Excellent

Choice	Total
A	2 participants
B	2 participants
C	2 participants
D	6 participants
E	0 participant

Help users recognize, diagnose and recover from errors

11. Did you know what needed to be done once the failure was notified?

    A. I knew I had to avoid the crash somehow

    B. I knew I had to apply the brakes

    C. I knew I had to overtake the vehicle in front

    D. I had no idea what to do

Choice	Total
A	6 participants
B	5 participants
C	0 participant
D	3 participants

Help and documentation

12. How helpful was the experiment briefing prior to the test?

    A. Yes, it was quite helpful

    B. Yes, that is all what I needed before the tests

    C. No, I was expecting a better briefing about the interface and the scenarios.

    D. No, I was expecting a better briefing about (Please specify) . . . .

Choice	Total
A	6 participants

B	6 participants
C	0 participant
D	0 participant