Adaptive Driver Information

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Abstract

New societal requirements and functional growth put new demands on future driver information. Simultaneously, new technology and IT capabilities make it possible to constantly adapt the information given to the driver for different reasons. Therefore, the aim of this thesis was to obtain an improved understanding and strengthen knowledge of the adaptive control of driver information to understand if, for what reason, when and where to use adaptive driver information (ADI). Some possible new means to support drivers are also suggested.

The main purpose of driver information is to support the driver in achieving goals such as a safer, more environmentally friendly, more efficient, legal and enjoyable transportation by providing correct information and feedback.

The methodologies included deductive, inductive, qualitative and quantitative research. Interviews, questionnaires, web surveys, simulator studies and data analysis were done.

ADI can support the driver throughout development of skills and when performing operational, tactical and strategic level tasks. Tasks related to setting goals for the driving task and encouraging good driving behaviour can also be supported. ADI can furthermore help drivers to stay within their comfort zone by visualizing risk or certainty, identify and thereafter adapt how a message is communicated to different personalities, maintain the driver’s mental workload within the safe task load area by reducing demand when it is too high, increase mental workload by an extra stimulating task during too low a mental demand, and minimize the risk for mismatches between effort and real demand.

ADI changes automatically, which may cause new and unpredictable issues reducing the purpose of driver information. These may include: mode confusion, function allocation, over and under trust, locus of control issues, skill degeneration and too low/high mental workload and can be summarized as automation induced issues. Research has suggested that the most efficient way to reduce these issues is to make the driver and the automation (the agents) get along together and become team players. The team players should share goals, show intention, show limits of performance, state etcetera. However, for cars, a consumer product in which visual demand is high, an approach can be where information vanishes or change level of abstraction when agents have become a “team”. This approach may be called “team building”.

Research and industrial contributions have been presented. Several examples of how ADI can be carried out have been suggested and some even illustrated.

Key words: Adaptive, automation, driving information, team player approach, uncertainty, mental underload, mismatch, Work Domain analysis, personality trait, Drowsiness
Acknowledgement

Writing this thesis has made me recognize new levels of frustration and confusion. However, thanks to a lot of people, it still has been also fun and very exciting.

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Urban Kristiansson has encouraged me and many others and taken Volvo Cars to a completely new level regarding research. Wow! Volvo Cars is now a future oriented company with the highest possible ambitions and that encourage research. Thank you for letting me take part in Volvo Car’s PhD program.

Without the support of the IVSS and FFI programs within VINNOVA and the world leading safety competence centre SAFER this project would be difficult to carry out. Thank you for your support and belief in the project.
Publications

This thesis is founded on the following publications.


Contribution: The study was carried out by Davidsson in collaboration with Brunel University in United Kingdom. The paper was written by Davidsson.


Contribution: The study was designed, and carried out by Davidsson. The method was developed together with Alm. The paper was written by Davidsson.


Contribution: The study was designed in collaboration with Alm. The study was carried out and paper written by Davidsson.

**Paper D:** Davidsson, S., Alm. (2014). *Drive and I tell you who you are*. Manuscript submitted for publication.

Contribution: The design of the study and the statistical analysis was done in collaboration with Alm. The main part of writing of the report was carried out by Davidsson.


Contribution: The design of the study, the statistical analysis and the writing of the report was carried out by Davidsson.


Contribution: Co-author on 50% basis.

Contribution: Research idea, hypothesis creation, study design, research leader, ran the main part of the simulator study.


Contribution: Research idea, Graphical design, hypothesis creation, design of simulator scenario.
# List of abbreviations

Commonly known abbreviations are excluded.

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<thead>
<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>4G</td>
<td>Fourth generation mobile communication</td>
</tr>
<tr>
<td>ACC</td>
<td>Adaptive Cruise Control</td>
</tr>
<tr>
<td>ADI</td>
<td>Adaptive Driving Information</td>
</tr>
<tr>
<td>ADAS</td>
<td>Advanced Driver Assistance System</td>
</tr>
<tr>
<td>AIDE</td>
<td>Adaptive Integrated Driver-vehicle Interface</td>
</tr>
<tr>
<td>CFM</td>
<td>Context Function Matrix</td>
</tr>
<tr>
<td>C2C</td>
<td>Car to Car communication</td>
</tr>
<tr>
<td>C2I</td>
<td>Car to Infrastructure communication</td>
</tr>
<tr>
<td>CWA</td>
<td>Cognitive Work Analysis</td>
</tr>
<tr>
<td>DIMON</td>
<td>Driver Monitoring system</td>
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<tr>
<td>DVE</td>
<td>Driver Vehicle Environment</td>
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<tr>
<td>EID</td>
<td>Ecological Interface Design</td>
</tr>
<tr>
<td>FOT</td>
<td>Field Operational Test</td>
</tr>
<tr>
<td>FP</td>
<td>Functional Purpose</td>
</tr>
<tr>
<td>GEMS</td>
<td>Generic Error Modelling System (Reason, 1990)</td>
</tr>
<tr>
<td>GIDS</td>
<td>Generic Intelligent Driver Support</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HD</td>
<td>High Definition</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interaction</td>
</tr>
<tr>
<td>IDIS</td>
<td>Intelligent Driver Information System</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation System</td>
</tr>
<tr>
<td>IVIS</td>
<td>In-Vehicle Information System</td>
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<tr>
<td>LDW</td>
<td>Lane Departure Warning</td>
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<tr>
<td>LKA</td>
<td>Lane Keeping Aid</td>
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<tr>
<td>LoC</td>
<td>Locus of Control</td>
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<tr>
<td>MABA-MABA</td>
<td>Men Are Best At – Machine Are Best At</td>
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<tr>
<td>MART</td>
<td>Malleable Attention Resource theory</td>
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<td>MRT</td>
<td>Multiple Resource Theory</td>
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<tr>
<td>NHTSA</td>
<td>National Highway Traffic Safety Agency</td>
</tr>
<tr>
<td>PF</td>
<td>Physical Function</td>
</tr>
<tr>
<td>rpm</td>
<td>Revolutions per minute</td>
</tr>
<tr>
<td>RQ</td>
<td>Research question</td>
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<tr>
<td>SA</td>
<td>Situation awareness</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SRK</td>
<td>Skill-, Rule- and Knowledge-base</td>
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<tr>
<td>SS</td>
<td>Sensation Seeking</td>
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<tr>
<td>SSS</td>
<td>Sensation Seeking Scale</td>
</tr>
<tr>
<td>SWRR</td>
<td>Steering Wheel Reversal Rate</td>
</tr>
<tr>
<td>TAM</td>
<td>Technology Acceptance Model</td>
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<tr>
<td>WDA</td>
<td>Work Domain Analysis</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Wireless</td>
</tr>
<tr>
<td>XSGA</td>
<td>Screen resolution (1280 x 1024)</td>
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1 Introduction
This chapter describes the background of the project, earlier work, definitions, aim and scope, delimitations made and the project’s procedure.

1.1 Background – The past, the present and the future

1.1.1 The past
Despite that “the only thing we learn from history is that we learn nothing from history” (Hegel, n.d.), let's first take a huge leap back in history. We have had "cars" since 1769 when Joseph Cugnot built the first steam driven vehicle (see figure 1) in Paris (Hansson, 1990). The purpose of the car was to transport guns and the top speed was as high as 4 km/h.

Figure 1. Joseph Cugnot's steam vehicle.

Knowledge about Cugnot’s car’s instrumentation is limited but the first cars’ instrumentations’ main task was most likely to show the status of the vehicle (such as steam pressure) in order to avoid breakdowns that could lead to accidents or high costs. Unfortunately, Cugnot's “car” crashed into a wall in 1771 due to a lack of the most fundamental safety equipment, brakes. The first car accident was a fact (Hansson, 1990).

Later in the twentieth century when cars for the public were available, car instrumentation was not much more developed. Ford model T's instrumentation (1908-1927) was limited to ignition switch and an Ampere meter. Speedometers, fuel gauge or tachometer were introduced later.

1.1.2 The present
Cugnot’s very early vehicle crashed but unfortunately the present safety figures are not very encouraging. During 2009, 319 persons died and 3127 were severely injured in traffic accidents in Sweden alone (Swedish Transport Administration, 2012) and approximately 1.24 million deaths occurred on the world’s roads in 2010 (World Health Organization, 2013).
Another effect of transportation is that it can be harmful to the environment, both globally and locally. Worldwide, the fossil fuels used for transportation contribute to over 13% of greenhouse gases (Walser, 2013).

Furthermore, the inefficiency of transportation is enormous. In London, for instance, 20% of commuters spend more than two hours a day travelling to and from work, which adds up to one working day a week (Travel in London, 2009).

Despite the advanced information technology that is available, most cars have nothing or very little to directly support the driver in areas such as those mentioned above. Much of the information that is provided is highly abstract and needs to be interpreted to give meaning and be useful for the driver.

The purpose of the tachometer, for instance, is to show how many revolutions the crank shaft turns in one minute. Some drivers use it to optimize torque and to drive in an environmentally friendly way. It often has a red field at the upper end of the scale that indicates too high rpm. It is sometimes used to see if the engine is running, which can be hard to hear. The scale does not indicate the optimal time to change gear. That is something you have to learn. Furthermore, most cars also have a protection system against running the engine at too high rpm, which makes the red part useless. Strangely, it is also common to have a tachometer in cars with an automatic gear box.

It could be argued that the reason for having a speedometer is limited to showing how far you travel in one hour and, if you have knowledge about the current speed limit, it can also be used to maintain a legal speed. Some may think that it has to do with safety but it is argued in this thesis that there is a weak relation between showing the speed and the parameters behind safety. It does not show kinetic energy, which is transformed into mechanical energy that collapses the car's body in a car crash, and it does not show braking distance.

Despite the intensive work on safer car technology and roads, more efficient engines, power trains, new fuels and new infrastructure, there is also always a potential in the human part of the system to improve safety, reduce the use of energy and improve the efficiency of transportation. The decisions made by the driver are often based on information from the vehicle, the infrastructure and new technology such as GPS, radar sensors, optical sensors, Wi-Fi, 4G and high resolution displays. According to Wilbers (1999) drivers can reduce the use of fuel by 5-10% by coaching information about how to drive more efficiently. This is far more than most technical solutions can do. It therefore seems that there is a great potential and the right opportunity to improve driver information also.
1.1.3 The Future
During the work with this thesis I have been asked to look into the future of technology (very few asked about the future of drivers’ needs!). A simple matrix showing technology 15 years ago, the current technology and a linear approximation about the technology level in 15 years from now was created from data found in for instance Wikipedia (the figures are not exact). A linear approximation is probably an under-estimation if Moore’s law (Moore, 1965) remains valid in the future, but the table speaks for itself.

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2010</th>
<th>Factor</th>
<th>2025</th>
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<tbody>
<tr>
<td>The largest hard drive size was…</td>
<td>1 Gigabyte</td>
<td>3 Terrabyte</td>
<td>3000</td>
<td>9 Petabyte</td>
</tr>
<tr>
<td>CPU clock frequency</td>
<td>100 MHz</td>
<td>8580 MHz</td>
<td>86</td>
<td>738 GHz</td>
</tr>
<tr>
<td>Graphics</td>
<td>1280x1024 (XSGA) 17” screen</td>
<td>960x640 pixels on a 3.5” display</td>
<td>11.5</td>
<td>&gt;&gt; Eye resolution</td>
</tr>
<tr>
<td>Flash memories</td>
<td>2 MB</td>
<td>64 GB</td>
<td>32000</td>
<td>2.05 PB</td>
</tr>
<tr>
<td>USB memory stick came as late as 2000</td>
<td>8 MB</td>
<td>32 GB</td>
<td>4000</td>
<td>128 TB</td>
</tr>
<tr>
<td>Camera resolution</td>
<td>0.35 Megapixel</td>
<td>41 Megapixel (2012 Nokia Smart phone)</td>
<td>117</td>
<td>4.8 GigaPixel</td>
</tr>
</tbody>
</table>

Table 1. Development of technology and the under-estimated future (?)

It is of course hard to foresee the future but it is certain that cars in the future can share data through connectivity: they have a better display technology than what the eye actually needs, we have to learn new high numbers such as “Peta” (=1015) and it is noteworthy that the largest hard drive size in the year 2025 (9 PB) equals 50 years of movies with High Definition (HD) quality.

It may be the time not to limit ourselves to what it is possible to do with the technology we have today but rather start to discuss what we need and want to have (even if it is a tachometer in cars with an automated gearbox) in our cars in the future. A strategy would be to start to consider the drivers’ goals, their differences (both between drivers and within the same driver), new needs and what customers dream of, and start to create great user experiences for instance by Adaptive Driver Information.

1.2 Earlier work
Work on adaptive driver information (ADI) has been done before. The Generic Intelligent Driver Support project (GIDS) (Michon, 1993) was one of the pioneers and much of the thoughts behind today's navigation and warning systems stem from that research. Their idea was that sensors sensed the environment; a driving task model and a user model were compared and, if a mismatch was identified, the diagnostician
detected differences between the behaviour of the actual driver and the reference driver. The “teacher” decides how, in which information channel, in which order and when (how urgent) it must communicate with the driver.

Figure 2. Conceptual model for GIDS.

The AIDE project (Engström et al., 2004) included adaptability of an integrated HMI to the current driver state/driving context. The aim was to create an adaptive interface that was configurable for different drivers’ characteristics, needs and preferences. Feigh, Dorneich and Hayes (2012) shaped a systematic framework characterizing adaptive systems. The framework contained two parts that: categorize ways in which adaptive systems can change their behaviour (function allocation, interaction, content, task scheduling) and exemplify trigger mechanisms through which adaptive systems can sense the current situation and decide how to adapt (system, world, task/mission, spatio temporal and human state).

This thesis’ perspective is slightly different from that of GIDS or AIDE and the framework by Feigh, Dorneich and Hayes (2012). It includes workload management but has been extended also to include, for instance, more of the effects of low workload, what information a driver wants and needs, an analysis of the purpose of driver information and personality. It also puts more effort into the possible problems with automation and includes new aspects of adaptive control that have so far not been dealt with. Furthermore, the thesis also, to a small extent places light on other aspects of driving than safety, such as green driving, efficiency and that people often drive because they enjoy it.
1.3 Definitions

<table>
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<th>Term</th>
<th>Definition</th>
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<tr>
<td>Driving information</td>
<td>Information that intends to support the driver’s goals. This information may be within the car but in this thesis it may also be elsewhere such as in a computer displaying the weather forecast in order to support the driver in his or her strategic planning of a route.</td>
</tr>
<tr>
<td>adaptive</td>
<td>An <em>adaptive</em> display is one in which the underlying system is in control of adjusting information presentation (Hameed and Sarter, 2009)</td>
</tr>
<tr>
<td>adaptable</td>
<td>An <em>adaptable</em> display is one in which the human operator has the control over any adjustments to the way information is being presented based on his/her needs. (Hameed and Sarter, 2009)</td>
</tr>
<tr>
<td>Automation</td>
<td>The properties of a technical system to perceive, analyse, decide and or act on its own under different degrees of human involvement (Andersson, 2014)</td>
</tr>
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Table 2. Definitions

1.4 Aim and scope

The aim of this thesis is to obtain an improved understanding of adaptive driving information (hereafter called ADI). The aim is also to bring further current knowledge and strengthen knowledge in the adaptive control of driver information, to give some possible examples of directions and thereby make possible new means to support drivers (being well aware that this is not a “traditional” research question, it is still important to exemplify how ADI can be carried out to make the result useful).

In this thesis, this is achieved by focusing on the information wanted and needed by the driver at the right occasion during non-critical driving and in an appropriate manner. The thesis aims also to identify what information should be adapted and to find ways to help drivers reach their goals, which is mainly, but not only, safety.

These aims have been broken down into four main research questions:

*Research questions*

RQ1. What are the purposes of future driver information?

RQ2. What governs adaptive driver information?

RQ3. What are the negative effects of adaptive driver information?

RQ4. How can adaptation be carried out?
1.5 Delimitations
This thesis treats driver information up to a level where it is possible to avoid warning and thereby keep the driver in the comfort zone (i.e. avoid inconvenience). This may be explained as category 1 according to the classification of Ljung Aust (2009) (see figure 5). The idea is that if a warning occurs, if the driver is disappointed by high fuel consumption, or if the driver, without being aware of it, is speeding, the driver information system has failed to support the driver. Gentle and non-intrusive information during non-critical periods about how to drive more safely, greener and so on may, instead of warnings, feel less inconvenient.

This thesis focuses on an adaptive user interface where information is changed automatically. A parallel project to Adaptive Driving Information resulted in a thesis called “The User as Interface Designer” (Normark, 2014), which handles driver information from a less automated perspective than the current thesis where drivers choose information they want or need manually.

Vehicle state is left out of this thesis despite that it is suggested by for instance Alfredson (2007) to be treated as a part of an adaptive information system and that some safety systems and systems depending on for instance brakes may respond earlier if the car’s status is poor.

1.6 Procedure
This section briefly explains the procedure from identifying important research domains until the thesis was written. Figure 3 illustrates the progress of the work in the project: research domain, the studies and the papers generated from the studies on a timeline.

The starting point was to analyse the transportation system, defined as a complex sociotechnical system. The first study therefore investigated the purpose of driving information and the links down to each component in the system. This study is called Work Domain Analysis.

It was also early concluded that the particularly important components for an ADI such as mental workload and driver state had a common denominator, automation. The research domain of automation was therefore investigated. The Team player study applied the Team player framework to ADI, a framework that intends to reduce automation induced issues, a second study concerning automation investigated the effect of uncertainty information in automation. To understand more about the influence of the driver’s state a study called Drowsiness where the driver’s behaviour during the development of sleepiness was investigated.
Mental workload was investigated in two studies: the *Task pre-load* study investigated the effect of adding demand during low workload and the *Mismatch* study looked into the effect of mismatches between real world demand and drivers’ invested effort.

In many studies the human seemed to be the component in the complex system that caused the largest variation of the systems performance. The need for a deeper understanding of how people behave led to a study about how one *personality*, sensation seekers, behave in traffic and how design can counteract poor behaviour.

From here on, the studies are named in accordance with figure 3. For instance, in the field of *automation*, the *Team player* study and the *Uncertainty* study took place. These studies resulted in *paper C and paper H*.

![Figure 3. Fields, studies and papers in this thesis](image-url)
1.7 Outline
The thesis follows a structure starting with a discussion of previous, present and coming driving information. This is followed by descriptions of earlier work, definitions, aims, research questions, limitations, research approaches and the methods used.

Chapter 2 presents the research approaches and the used methods.

Chapters 3-5 are the frame of reference and describe the theoretical background. Results from the studies are integrated in this section and treated equally with other research.

Chapter 6 describes how adaptive driver information can be carried out. Results from the studies are integrated with knowledge from others in a discussion of how adaptive driving information can be used in industrialization. Possible solutions for the ADI context are suggested. This chapter may therefore also be said to include results for industrial implications.

Chapter 7 is a collection of summaries of the main studies in the project.

Chapter 8 discusses the methodological considerations that were addressed in the project.

The conclusions drawn in the project are dealt with in Chapter 9. This is followed by Chapter 10, which gives suggestions for further research in the field of adaptive driver information.

Eight papers are appended to this thesis.
2 Method

This section describes research theory and methodology used in the project. For a more detailed description of the methods used in each study see the particular paper. The consequences of the methods selected for the reliability and validity of the results will be discussed in Chapter 8, Methodological considerations.

2.1 Research theory

Research is either done in order to answer questions put forward by theoretical considerations (deduction) or the reverse, viewing theory as something that occurs after the gathering and analysis of data (induction) (Starrin and Svensson, 1994). The work carried out in this thesis has used both deductive and inductive research.

The Personality study investigated whether it was possible to predict a sensation seeking score from driving characteristics data; the Task pre-load study looked into the effects on performance of adding a pre-load and the Uncertainty study investigated whether uncertainty information is beneficial for the calibration of trust. These studies may be regarded as deductive research. In fact, these studies may even fall under the term hypothetico-deductive (Popper, 1959) since they have a hypothesis that could be falsified.

In the Context study a theory is shaped regarding how information should be displayed to the driver in different contexts based on data from interviews and rating of functions. In the Drowsiness study it was concluded that one of the problems with sleepiness research is the mismatch between researchers and common drivers about what they believe are working methods to counteract sleepiness. Furthermore, the Mismatch study resulted in a theory based on a literature study of workload. These studies may represent examples of inductive research.

The work has also used both qualitative and quantitative research. Qualitative research aims to collect an in-depth understanding of human behaviour and the reasons that govern such behaviour. The Context study tried to form an in-depth understanding of drivers’ behaviour in different contexts by asking and encouraging to mentally simulate driving and then discussing freely what they think of, how they act etcetera in a context. Similarly the Delphi (Kirwan and Ainsworth, 1992) procedure used in the Team player study is also an example of qualitative research.

The aim of quantitative research is to develop and use mathematical models, theories and/or hypotheses applicable to phenomena. In the Personality study the driver’s sensation seeking score was correlated to different driving parameters. The independent variables were then used to study whether it was possible to predict a sensation seeking score. This was done with a multiple regression analysis. The Uncertainty and the Task pre-load studies are also typical quantitative studies.
2.2 Test samples

Several categories of test samples were used in the different studies. Two studies used experts and five studies used different sets of car drivers.

In the Context study the different contexts and functions were decided in a group discussion by five Safety and Human Machine Interaction (HMI) experts at Volvo Car Corporation and Luleå University of Technology. The experts were also used when developing the Context/Function Matrix (CFM).

Two female and eight male experts in design of Active Safety systems, design of Driver Information Systems and HMI design at Volvo Car Corporation, Luleå University of Technology and Chalmers participated in the Team player study.

In the Context study 33 Swedish private car drivers took part, 14 men and 19 women, with an average age of 42 years, ranging between 20 to 69 years, and were recruited in the Gothenburg region of Sweden.

The data material for the Personality study was collected in the European Large-Scale Field Operational Tests on In-Vehicle Systems (euroFOT). Data from 136 participants (55 women and 81 men) with an average age of 46.7 years (SD=9.0) and a range from 18 to 62 years were included in the study.

The survey in the Drowsiness study was completed by 44 men and 33 women recruited from different social media such as Facebook. The average age among the participants was 44.5 years (SD= 9.4). The number of years with a driving license was in average 25.6 years (SD= 9.5). The survey was in Swedish and thus all of the subjects knew Swedish.

Twenty-seven participants took part in the Task Pre-load study, 14 of whom were male. The average age of the sample was 36.0 (SD= 12.7), and 14 participants were randomly allocated to the low workload condition; the average age was 34.1 (SD = 12.6). In the high workload condition, there were 13 participants (six males) with an average age of 38.5 (SD= 13.1). Participants were recruited from the Brunel University driver participant pool.

A total of 61 participants (31 male, 30 female) between 27 and 58 years with an average age of 41 years took part in the simulator experiment in the Uncertainty study. The participants were selected from a population of 488 Volvo employees, mostly non-technical personnel.
2.3 Data acquisition

Several methods were used to gather data for the work. Literature studies were combined with interviews, questionnaires and ratings to capture relevant information from both real road driving and pre-defined simulator driving.

2.3.1 Literature studies

Literature studies were done in all studies. However, the Team player study required insight in a new area, automation, and from different domains such as aviation, power plants and shipping, which required an extensive literature study. Mental workload is a topic strongly related to ADI. Therefore, it was also necessary to create an in-depth understanding of the term and terms closely related to workload. A broad literature study was therefore needed in the Mismatch study.

2.3.2 Interviews

Interviews were used in the Context study. The purpose of the interview was to try to make the participants think beyond today's design of cars and to gather data for an understanding about how people think in different contexts. An interview method of particular interest is the already mentioned Delphi procedure (Kirwan and Ainsworth, 1992) that was used in the Team player study. Opinions of experts were first collected individually; the expert was then given the judgment from the previous experts and could then re-evaluate his/her own judgment. This reduces bias between group members and makes it possible to gather quantitative data. The method was modified such that, instead of having individual feedback sessions after all had been interviewed, all experts were called to a focus group meeting.

2.3.3 Questionnaires

Paper questionnaires were used in the Personality study. Background data such as gender, age and annual mileage were collected together with a modified questionnaire based on the Zuckerman Sensation Seeking Scale (SSS; Zuckerman, 1994). The answers on the SSS ranged between “do not agree at all” to “agree very well” in four discrete steps. The lowest level of sensation seeking was given 1 point and the highest 4. No weighting of the questions was done. There were a total of 20 questions, which gave a highest possible score of 80 points and a lowest of 20 points.

In the Task Preload and Uncertainty studies background data were collected using a paper questionnaire. In the Task Preload study the NASA R-tlx method (Hart and Staveland, 1988) was also used to retrospectively collect data about the drivers' workload. In the Uncertainty study the paper questionnaire was used to collect subjective data about for instance trust in the technology.

An Internet questionnaire was created in the Drowsiness study using the tool “Surveymesh” (www.surveymesh.se). The survey contained background questions
about gender, age, years holding a driving license and how many kilometres they
drove per year. The subjects were then given the opportunity to choose one or several
of the 14 activities that they used if they felt tired. They were also asked if their
activity worked, how often they used the activity, on which road type they most easily
get tired, after how long a time and at which time they get tired. The different
activities presented were not randomly varied due to limitations of the "Surveymesh"
tool.

2.3.4 Ratings

Ratings were used in the Context study. Nine pictures illustrating one context group
were displayed on a paperboard (see figure 4). Among the different participants, the
pictures were randomly mixed on the board to avoid order effects. The pictures
showed different viewing angles, such as from inside the car and a bird’s eye view.
The contexts “queue” and “before / after” driving were found difficult to illustrate by
pictures. Instead, written text was used. The participants were then asked to grade the
physical function from 1-5, where 5 is very important and 1 is not important; if the
function was not applicable, inappropriate or dangerous for the context, it was
possible to put the function in a waste bin.

The participant took a card on which the physical function was printed from a
randomly mixed stack of cards, read the physical function and the number aloud (then
often looked at and browsed the pictures) and decided which grade to give the
function. The card was put in a cup labelled with a grade or the waste bin symbol
placed below the pictures.

![Figure 4. Paperboard used for rating of functions in different contexts. This particular example is the context of Highway driving.](image-url)
2.3.5 Simulator studies
Simulator studies were done in two studies. In the Task pre-load study a very low demanding road environment was developed in order to result in a driving performance reduction (Young and Stanton, 2002). Another road with a more “normal” demand was also developed. The driver was treated with or without a task pre-load which resulted in a 2x2 design. Driving data such as Standard Deviation of Lateral Position (SDLP) and response time to two brake events were collected.

Simulator driving was also used in the Uncertainty study. The participants drove the car simulator through a snowy and foggy two lane country side road. Depending on the weather conditions, the degree of visibility varied from 0% to 100%. When the visibility was worst, the car simulator could no longer follow the road marks, the car uncertainty representation showed the lowest level and the automation could no longer manoeuvre the car. The time to take over was measured.

2.3.6 Field studies
The material for the Personality study was collected in the European Large-Scale Field Operational Tests on In-Vehicle Systems (euroFOT). The data consisted of the Volvo Cars part of the euroFOT project (Bärgman, et al., 2011). One hundred cars were equipped with a data acquisition system and driven by regular drivers for one year. Over 25,000 hours of naturalistic driving data such as GPS signals, CAN data and video recordings were collected during the study.

2.4 Data analysis
Data analysis was necessary after the simulator driving in the Task pre-load and the Uncertainty studies. A one-way Anova analysis was used in Uncertainty to investigate whether there was a significant difference between the different conditions. In the Task pre-load study the frequency of crashes and missed Peripheral Detection Tasks (PDT) were analysed with the chi-square method, and a 2x2x2 way Anova was used to compare the within-subjects factors of pre-loading task and pre- or post-critical event, against the between-subjects factor of workload condition.

Correlations between the Sensation Seeking score and driving behaviour were calculated, and multiple regression analysis was done in the Personality study to see if it was possible to predict an SS score and how well.

In the Context study, mean and standard deviation was used to interpret the results of the ratings of functions in different contexts. The ratings’ average gave a hint about what functions are needed or wanted, and the standard deviation indicated the extent to which there is consensus about each function in the given context.
### 2.5 Summary of methods used in the appended papers

<table>
<thead>
<tr>
<th>Study name</th>
<th>Research theory</th>
<th>Data acquisition</th>
<th>Subject/sample size</th>
<th>Dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Domain Analysis</td>
<td>Inductive</td>
<td>Workshops, company documents</td>
<td>4 experts</td>
<td>N/A</td>
</tr>
<tr>
<td>Context</td>
<td>Inductive</td>
<td>Simulation interview, interview, questionnaires, ratings</td>
<td>33 swedish private car drivers</td>
<td>N/A</td>
</tr>
<tr>
<td>Team Player</td>
<td>Inductive</td>
<td>Literature studies, Delphi procedure, focus group,</td>
<td>10 Experts</td>
<td>N/A</td>
</tr>
<tr>
<td>Personality</td>
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<td>Field data, questionnaires, statistical analysis</td>
<td>136 participants</td>
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</tr>
<tr>
<td>Drowsiness</td>
<td>Inductive</td>
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<td>N/A</td>
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<td>Mismatch</td>
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<tr>
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<td>Questionnaires and simulator driving</td>
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<td>Uncertainty</td>
<td>Deductive</td>
<td>Questionnaires and simulator driving</td>
<td>61 Volvo Employees</td>
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</tr>
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</table>

*Table 3. Summary of methods used in the different studies*
3 The purpose of future driving Information (RQ1)

This chapter gives a background to why there is a need for adaptive driver information and what the purpose of the future driver information may be.

3.1 Background

The driving task has changed dramatically through history. Cars do not break down as often, traffic is far denser, at least in the larger cities, and other issues, such as carbon footprint and transportation efficiency, are more important than before. The purpose of driving information may slowly have shifted from supporting reliability to other purposes. This section therefore discusses these purposes.

*Functional growth* will continue, not only within the area of car entertainment. Improved maps, new sensors, connectivity, car to car (C2C) and car to infrastructure (C2I) will increase the number of in-vehicle information system (IVIS) functions. This together with a stronger societal push from authorities such as the National Highway Traffic Safety Agency (NHTSA) about reduced distraction (National Highway Traffic Safety Agency, 2010) (for a definition of distraction, see for instance Regan, Lee and Young, 2009) will most likely make it difficult or even illegal to show all information simultaneously.

Often, functional growth is driven by what the technical development can achieve rather than by actual human needs. This creeping featurism (Norman, 1988) is the propensity to add to the number of features that a device can do, often extending the number beyond all reason. Whether we like it or not, it is a realm in which functions come, develop, sometimes survive and sometimes also vanish. This featurism may be harmful and add to distraction if it is implemented in a careless manner.

Functional growth and technological development can of course also be positive. With better display quality, new functionality can be implemented that was not possible before. Designers can be more illustrative and pedagogic when it comes to driver information. It is also easier to a higher degree to integrate information that belongs together from the user’s perspective. For instance, speedometer, speed limit set speed, adaptive cruise control set speed and present speed limit can all easily be integrated with each other, which may enable more information without being distracting. This was not possible when the gauges were physical.

Connectivity enables information about for instance road condition to be collected by one car and then further distributed and shown in several cars, and cloud services reduce the handling of mobile media such as CDs while driving.
Globalization makes it more and more necessary for manufacturers to adapt to different market needs and driving behaviour, an issue whose importance is described for instance by Lindgren (2009).

Groeger (2000) suggests that driver behaviour is to a large extent goal-directed, and drivers may have various goals (safety, speed, economy etc.) that are mainly positively correlated but might sometimes be in conflict. Drivers evaluate these conflicts and plan their driving accordingly.

3.2 The purpose
The goals of driving could and perhaps even should be reflected in the purpose of driver information and it was concluded early in the project that an analysis of the root purpose of driver information and its relation to today’s and future functions must be done.

ADI may have the features necessary to reduce the effect of functional growth, reduce clutter, optimize workload and still support the driver's different goals of driving. One of the prerequisites when the project started was to investigate whether ADI could help to solve issues such as functional growth and if it could function as an enabler for new technology that would not otherwise be possible to squeeze into the driving information system.

3.3 Traffic – a complex sociotechnical system
Hollnagel (2004) states that complex sociotechnical systems “consist of multiple parts that depend on each other, and there is only a limited possibility of delaying processes or in carrying out actions”. The transportation system contains many different and interacting sub-systems such as road users, roads, manufacturers and authorities etc. and may therefore be regarded as a complex sociotechnical system.

A characteristic property of a complex system is that it is not possible to predict everything that might happen in the system (Hollnagel, 2004). Accidents on the road, problems associated with the infrastructure and other unexpected events may be some examples of events that are very hard to predict. Consequently, it seems important to provide car drivers with some support to meet events that involve problem solving or knowledge based behaviour.

3.4 Cognitive Work Analysis (CWA) Framework
Cognitive Work Analysis (CWA) is a framework that was developed to model and make complex sociotechnical work systems understandable (Vicente, 1999). Several studies have used CWA to study vehicle design and to suggest new or improve driver support systems such as Advanced Driver Information Systems (ADAS). Salmon, Regan, Lenne, Stanton & Young (2007) used the first step, Work Domain Analysis
(WDA), in CWA to study Intelligent Transport Systems (ITS). A study by Birrell, Young, Stanton & Jenkins (2008) used CWA to develop a technological device that would encourage drivers to drive in a safer and greener (i.e. more environmentally friendly) manner through on-board advice and post-drive feedback. Seppelt and Lee (2007) applied ecological interface design (EID) to create a visual representation of Adaptive Cruise Control (ACC) behaviour. Jenkins, Stanton & Walker (2007) used the first steps in CWA and developed a new approach to designing lateral collision warning systems.

The driver could both be overloaded with information that is not adequate for a specific situation and also lack information that is needed in relation to the driving task and individual driver goals (Salmon, Regan, Lenne, Stanton & Young 2007). A WDA could potentially identify the information needed by the driver to achieve the different goals.

Thus, it was reasonably obvious that CWA was an appropriate approach and that the first step, WDA, was a suitable method to use to answer RQ1.

In the Work Domain Analysis study the relationship between the Functional Purpose (FP; the reason why the system exists) and the different Physical Functions (PF; the resources of the system) of driver information was investigated using Work Domain Analysis (WDA; Vicente, 1999).

The first step in the WDA is to create the FPs. Salmon, Regan, Lenne, Stanton & Young (2007) made a WDA for the Victorian road transport system and found that the FP was to provide safe, efficient and accessible mobility, and Stoner, Weise and Lee (2003) suggested that the functional purposes are to determine whether the driving domain up to a mile (~ 1.6 km) from the front of the car is safe, efficient, rapid and pleasurable transport. The Work Domain Analysis study resulted in a fifth FP, “legal driving”. The reason for that is that some of the functions in the car can only or mainly be explained by the purpose of legal driving and that the links to other purposes such as “safety” are weak.

The FPs of driver information suggested by the Work Domain Analysis study and the answer to RQ1 are to support transportation that is:

- Safe
- Efficient
- Environment friendly
- Legal
- Enjoyable (includes aspects such as tradition, “because I’m used to having it”, “feels good” etc.).
4 What governs adaptive driving Information? (RQ2)

This chapter gives a theoretical background about possible factors that could induce changes of the ADI system. Each area includes a theory description, a statement of what is relevant for the driving information context and/or results from studies done by the author of the present thesis.

4.1 Background

According to GIDS (Michon 1993), the adaptive system compares the user model with a reference model and, in Feigh, Dorneich and Hayes (2012), adaptation triggers are used to decide when and how to change the system’s behaviour or properties. Both can be argued to try to balance the system.

In this thesis the factors that govern ADI to change behaviour or properties are called input factors. Input factors are areas that may affect the behaviour of the system. For instance the system’s sensors may identify that a driver is more easily getting tired in comparison with others (Reference model). The ADI may thereafter be able to initiate effective countermeasures such as stimulating the driver mentally.

Thus, what are the different input factors that change the information to the driver so that the system balances? A starting point may be Alfredson (2007), who suggests that an ideal Situation Awareness (SA; more about SA later) supporting system should include a dynamic adaptation of interfaces to current vehicle status, situational conditions and contextual prerequisites as well as the individual's status, operator performance and historical behavioural data. Furthermore, Hoedemaeker and Neerincx (2007) suggested that factors such as driver state, the vehicle, the surrounding environment and the different in-car tasks should influence adaptability.

Feigh, Dorneich and Hayes (2012) call the input factors “triggers”. Triggers identify when to start, duration and when to finish the adaptation. These could be:

- **Operator-based.** Triggered by the operator directly or by a system assessment of the operator state.
- **System-based.** Current or predicted states of the system and or different modes of system operations.
- **Environment-based.** States of the environment or events external to the operator and the system.
- **Task- and mission-based.** Driving is typically composed of a comprehensible set of goals and sub-goals and accomplished by a set of tasks.
- **Spatiotemporal.** Time and location.

Most of these triggers and a few additional ones will be dealt with in this section, but often under other terms.
The input factors that may initiate changed system behaviour in this thesis are: level of control, risk, personality trait, skill and historical data, information processing, mental workload, context, traffic situation, driver state, age and gender.

4.2 Concepts and models of driving and drivers
An understanding of what the driving task is, what driver information is and how drivers behave is needed when designing a driver information system in general. This section briefly describes a few of the most influential models in the driver information context. The different models can serve as input to identify what support a driver needs throughout the driving task. These models can be seen as reference models in the GIDS concept (see figure 2).

4.2.1 Level of control
Drivers’ objective needs may be described by Michon’s (1985) taxonomy about strategic, tactical and operational levels of control. The strategic level consists of route planning according to defined goals, such as minimum travel time or avoidance of unattractive routes. The tactical level involves manoeuvres related to interactions with other road users and the road layout, e.g. negotiations at intersections, and the operational level consists of the actions with the vehicle controls: steering, changing gear, braking etc.

The higher levels influence the lower ones and, for the driving task, a driver may need support on all three levels. On the operational level, the introduction of Advanced Driver Assistance Systems (ADAS) has offered the driver warnings or mitigations. Systems such as distance alert, which informs the driver about a dangerously short headway to another vehicle, can be described as tactical support. To support strategic tasks, cars are equipped with trip computers that can calculate the distance that may be driven before the fuel tank is empty. Navigation systems can also be included in this category. However, it can be still be argued that most of the new systems mainly offer support at the operational level and less so on the strategic level.

In addition, strategic decisions seem to be controlled by an even higher level. Motivation to drive more safely may depend on the driver's motives, self-control and personal values, which have been described for instance by Hattakka, Keskinen, Gregersen and Glad (1999). They therefore added a forth level, “goals for life and skills for living” on top of Michon’s taxonomy.

Likewise, research on the relation between attitude and behaviour has been performed within the framework of the “theory of reasoned action” (Ajzen & Fishbein, 1980). A person’s attitude toward a behaviour, subjective norm, and perception of behavioural control results in the creation of a behavioural intention. The more favourable the
attitude and subjective norm, and the greater the perceived control, the stronger is the person’s intention to carry out the behaviour.

It seems important to support the driver in the different levels of control. ADI may be able to support the different levels by enhancing the information needed and reduce unnecessary information in the three levels described by Michon (1993). ADI may also have the opportunity to encourage good behaviour and to support avoidance of poor behaviour by also including the forth level described by Hattakka, et al. (1999).

4.2.2 Risk
There are several theories regarding how drivers handle risk, for instance, the hypothesis of risk homeostasis (Wilde, 1982). The risk homeostasis theory suggests that everyone has his or her own fixed level of acceptable risk. When the level of risk of the individual's life changes, there will be an equivalent rise or fall in risk somewhere to bring the overall risk back into balance.

Summala (2007) puts forward a hypothesis that drivers normally keep each of a number of factors such as time to collision, smooth and comfortable travel, rule following and good progress of trip within a certain range, in a "comfort zone", rather than trying to find an equilibrium such as that described by Wilde (1982). This mechanism results in a comfortable state and is called "comfort through satisfying".

Ljung Aust (2009) was heavily influenced by Summala (2007) and proposed a categorization of active safety functions. The general purpose of active safety functions is to support successful adaptation to changes in the driving environment, which reduces the risk of safety zone boundary excess (see figure 6).

The first category (1) represents functions aimed at keeping the Driver Vehicle Environment (DVE) trajectory inside the comfort zone throughout the whole scenario.

This thesis treats the information needed up to category1. The purpose of the ADI is to influence the driver to change behaviour by advisory information in such a way that a warning rarely occurs. In addition, it seems reasonable to use these thoughts for other areas than safety. For instance, there may also be a comfort zone for fuel consumption, for illegal driving, for efficiency etc.
4.2.3 The accident prone driver - Personality Trait

The focus on the road user and possible ways to improve safety have led researchers to identify road users who are supposed to cause more accidents than the average road user. Tillmann and Hobbs (1949) introduced the concept of “the accident prone driver” and focused on some drivers’ social and psychiatric background. It is well known that different personality traits, defined as habitual patterns of behaviour, thought, and emotion (Kassin, 2003), are unfortunately more prone to end up in an accident than others.

One of the input factors to ADI may therefore be personality trait and, consequently, the question is whether it is possible to adapt driver information to support various personality traits.

Driving anger, sensation seeking, impulsiveness, type A behaviour and boredom susceptibility are often mentioned as being accident prone (Dahlen et al., 2005). This section highlights some of the most common personality traits that are claimed to affect safety negatively or are affected in other ways by the technical system.

Sensation seekers

One of the personality traits that is said to predict accident involvement is sensation seeking. Sensation seeking is “a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience” (Zuckerman, 1994). Jonah (1997) concluded that sensation seeking was significantly related to deviant
driver behaviours such as speeding, drunk driving, racing the car, high speed and low seat belt usage. Often their behaviour is explained by the idea that “high sensation seekers” are thought to seek out extra stimulation to achieve an optimal level of physiological arousal (Zuckerman, 1994).

Furthermore, Thiffault and Bergeron (2003) concluded that subjects who admit having fallen asleep at the wheel in the past are likely to score higher on the Sensation Seeking Scale (SSS) than those who claim not to have done so.

**Boredom susceptibility**

Driver boredom has received limited attention (Heslop, Harvey, Thorpe & Mulley, 2010) but it appears to be a blunder to ignore that some people get more easily bored than others. For instance, Thackray (1975) showed that even basic performance measures such as response time can be negatively affected by boredom and the cognitive state is more negatively affected by sleepiness if a person is easily bored (Taylor & McFatterb, 2002).

Furthermore, it seems that easily bored drivers also take actions against boredom that may be categorized as poor driving behaviour. Heslop (2014) found that drivers who are under-stimulated respond by driving faster in contrast to those drivers for whom under-stimulation is not an issue, and Eysenck, Pearson, Easting, & Allsopp (1985) observed relatively high scores for thrill-seeking and boredom susceptibility among convicted drivers.

**Type A personality**

The type A personality construct is seen as a global personality type including a number of different behaviours and characteristics such as impatience, competitiveness, aggressiveness and negativity and is result oriented (Friedman & Booth-Kewley, 1988). Nabi et al. (2004) found that type A drivers had an increased risk of road traffic accidents.

**Extraversion and Introversion**

Extraversion is often revealed by an outgoing, talkative, energetic behaviour, and Eysenck (1985) suggested that extraversion, counterintuitively, was caused by a chronically lower cortical arousal. This lower level of arousal is compensated by seeking stimulation, which results in extravert behaviour.

Extraverts are more sensitive to road monotony and consequently more prone to fatigue-related driving errors in low demanding roads (Thiffault & Bergeron, 2003). Furthermore, sleep deprived extraverts have also shown reduced cognitive performance (Taylor & McFatter, 2003) and been observed to perform worse in response time in logical reasoning and auditory vigilance tasks (Smith & Maben,
In measures of response time, extroverts detected fewer signals than did introverts during a vigilance task (Gange, Geen & Harkins, 1979).

One of the benefits of being an extravert is an improved attentional performance expected when mental demands are high, the task is unknown and the time interval between stimuli is short (Stenberg, Rosén and Risberg, 1990).

Introversion is demonstrated in more reserved, quiet, shy behaviour. This results in introverts being better at sustained attention (Casagrade, 2002) and a less stimulating environment suits the introvert. During higher demand, the introvert tends to become over-aroused, leading to a reduction in performance, whereas the extravert might reach a near to optimum level of arousal, leading to improved performance (Casagrade, 2002).

In a comparison between introvert intermediate and extrovert groups by Fine (1963), extraverts are involved in more accidents and violations than introverts, which may lead to increased odds for death owing to risky behaviour (Wilt & Revelle, 2009).

**Locus of control, Internal - External**

Rotter (1966) defined Locus of Control (LoC) is a personality attribute reflecting the degree to which a person normally perceives events to be under their own control (internal LoC) or under the control of powerful others or other external forces (external LoC).

Research on LoC among drivers has indicated that internal LoC is positively associated with alertness and that self-bias in accident involvement and externality are positively associated with aggression (Lajunen and Summala, 1995). Research has also shown that internally oriented people are more likely than externally to behave in a safe manner and care for the safety of others (Roberts & Geller, 1995).

Furthermore, LoC is one of the most important psychological factors determining a driver’s behavioural adaptation in general and drivers’ acceptance of new in-vehicle technologies in particular (Rudin-Brown & Noy, 2002). For instance, externals may rely on automation and believe that the system can do more than it really can, and Rudin-Brown & Parker (2004) demonstrated that drivers with an external LoC were more likely to trust the Adaptive Cruise Control (ACC) system, and that this slowed their responses to failures.

Internals, on the other hand, may shut the system off and lose the potential safety and convenience benefits from a system such as ACC.

**Summary of the accident prone driver - Personality traits**

When designing new technology, it seems important to consider personality traits. If not, the technology will not be used in an optimal way. For instance, LoC may be one
of the explanations behind the results in the *Context study* that showed that some drivers preferred to perceive and act by themselves and some accepted support from support systems. This may of course also affect the acceptance of automated systems such as ADI or autonomous vehicles (see also the section about automation induced issues).

### 4.2.4 Skill and historical data

Alfredson (2007) suggested that historical behavioural data should be used in the dynamic adaptation of the system. It seems fairly intuitive that an everyday drive to work requires other information than when going on a holiday in an unknown area. This may be described by the taxonomy of Rasmussen (1986).

Different sub-tasks of driving can be classified in the SRK taxonomy developed by Rasmussen (1986), that is, skill based, rule based and knowledge based behaviour. Well-practiced tasks, such as steering in order to follow the road, may be regarded as skill based processes. Other tasks, such as overtaking other vehicles, may be regarded as rule based processes. Relatively few functions in the car of today provide support for reducing errors for the knowledge based processes of car driving, such as diagnoses, decisions, troubleshooting and reasoning when meeting unexpected events or problems during a trip (c.f. Michon, 1993).

The Generic Error Modelling System (GEMS) by Reason (1990) is an error classification arrangement that is based on the SRK taxonomy. According to GEMS, the errors are different in the skill, rule and knowledge based levels. Slips are expected at the skill based level, errors in finding and applying diagnostic rules are expected in the rule based level, while cognitive mistakes (e.g. errors in problem solving) appear more often at the knowledge based level.

Another way to explain this may be to use the term *schemata* (Neisser, 1976). For instance strong schemata can develop during a very common trip (Engström, 2011), schemata that are hard to compete with for unexpected events. Such an event may be an accident, but an illustrative example is if the driver has been asked to re-route to buy milk, where it is likely that the driver forgets and follows the old track. This is similar to what Reason (1990) called “strong habit intrusion”.

Poor skill may be manifested in accidents, and novice drivers are in fact over-represented in accident statistics (Williams, 2003). Waller et al. (2001) showed a reduction in the odds of crashing of around 17 percent per year of licensing, with the highest decrease (22 percent) in the first year of licensing. In addition, the greatest reduction in crash rate occurred over the first two to three years since starting to drive, suggesting that increasing driving experience reduces the likelihood of crashes.
Consequently, an ADI needs to know drivers’ development of skill and be able to adapt thereafter. In well-known areas, in unknown areas, and among novice drivers and experienced drivers, support may possibly not be given in the same ways.

4.2.5 Information processing
The famous model of human information processing (Wickens & Hollands, 1999) has had a great impact on research in the field of engineering psychology. This is a model that describes sensory processing, perception, cognition, memory and response selection and execution (see figure 6).

![Image of the Information process](image)

**Figure 6. The Information process**

In short, the stimuli (from warnings or the environment around the driver) access the brain through the different human sensors. This step has a great impact on the quality of the information that reaches the brain. The sensory data are then interpreted or given meaning in a step called perception.

The understanding achieved by cognition or perception of a situation often initiates an action. This is divided into response selection and execution. When an execution has been performed, new stimuli (feedback) are produced, which closes the loop.

The multiple resource theory (MRT) is a development of the information process with two extra dimensions, modalities and codes (see figure 7). MRT suggests that the three dimensions (stages, modalities and codes) are somewhat independent of each other (Wickens and Hollands, 1999). The vertical modality separation between auditory and visual resources can only be defined for perception, but the code distinction between verbal and spatial processes is relevant to all stages of processing. Lastly, the stage of processing dimension is represented with only two resources.
rather than three, suggesting that perceptual and cognitive processes demand the same resources.

An important implication of the difference between processing codes is the ability to judge when it might or might not be optional to utilize voice versus manual control (Wickens and Hollands, 1999). Manual control may reduce performance if there are heavy demands on spatial working memory, for instance while driving, whereas voice control may disturb the performance of tasks with heavy verbal demands.

Figure 7. The multiple resource theory

Another mode of communicating with the driver is by a haptic interface. Potentially, haptic interfaces would be able to complement visual and auditory modes and thereby improve communication. However, recent research shows that, when interacting with haptic interfaces in the presence of visual information, the haptic information is not instinctively taken into account and it seems better to facilitate the visual interaction rather than to replace it (Rydström, 2009).

The attention resource pool (the uppermost ellipse in figure 6) is used for selection of attention, working memory (for cognition), response selection and response execution, which all require attention resources; if demands exceed resource capacity, performance degrades. Attention is very important during driving and inattention is one of the largest contributors to accidents (Dingus et al., 2006).

The information processing models presented above have been criticized by many researchers (see for instance Engström and Hollnagel, 2007) for their description of people being reactors rather than actors and for the propensity to view attention
selection as a consequence of limited capacity. Engström, Markkula and Victor (2009) have a more action oriented perspective and instead consider selection as the main phenomenon of interest.

In Engström’s (2011) model, attention selection is defined as a selection of schemata (Neisser, 1976) and attention as the outcome of this procedure. The main idea is that schema selection occurs through interactive processes of collaboration and competition between schemata biased by input activation as well as different internal sources of activation.

In summary: The concept of the information process has already influenced the design of common driving information systems. However, some aspects need to be further looked into in the ADI context, for instance, a change in modality to avoid mental overload, adapting the sensory phase to age and how wrong schemata can be corrected.

4.3 Mental workload

One of the common thoughts regarding adaptive control system is that an adaptive interface should ensure that the driver remains in the “safe task load area” (Hoedemaeker and Neerincx, 2007), which is between a too high and a too low mental workload.

The relationship between demand and performance was first described more than a hundred years ago by Yerkes and Dodson (1908) with the use of mice that best learned a task with intermediate levels of electric shock; mice receiving negligible or a very high level electric shock did not learn as well. Whether or not electrified mice’ learning performance is relevant for human’s driving can be discussed, but this inverted U-shaped curve seems still to be relevant for many characteristics of alertness and attention. For instance, Mulder (1986) divided demand and performance into six regions in which the performance in the highest and lowest demand regions is affected negatively. In the first region (lowest demand), the operator's state and thereby performance are affected. In the second and fourth regions, performance remains unaffected but the operator has to add further effort to maintain performance. In region three, performance is optimal and the operator can easily cope with the task. In region five, efforts added are no longer sufficient and performance decreases; in region six, performance is at a minimum: the operator is overloaded.

4.3.1 High mental workload

As Mulder (1986) described, too high a demand can affect performance negatively. The consequence of driving is that this can lead to accidents (de Waard, 1996). One example of how workload affects driver performance was given by Alm and Nilsson.
(1995), where it was shown that reaction time was prolonged and headway keeping performance was reduced when a mobile phone was used while driving.

When discussing what a too high mental workload is, it is important to note that mental workload is both task dependent and person specific (de Waard, 1996), i.e. the same task demands does not result in an equal level of workload for all individuals. It is therefore necessary as much as possible also to consider individual differences when creating adaptive systems. Some drivers may have difficulty with a relatively low workload and therefore need more support, while others would be annoyed by the same level of support.

4.3.2 Low mental workload

It has also long been accepted in ergonomics research on mental workload that overload and underload are both harmful to driver performance (Hancock and Caird, 1993; Wilson and Rajan, 1995; Young and Stanton, 2002).

For instance, in the Malleable Attentional Resources Theory (MART) (Young and Stanton, 2002), underload is explained by a reduction of attentional capacity in conditions of too low a mental workload. As a result, any rapid increase in workload will be beyond the capacity limit of the operator – even if such a level of demand would ordinarily have been within their ability to cope.

One practical implication of MART as an explanation for underload is that attentional capacity may be optimized if the driver engages in some additional task activity (c.f. Young and Stanton, 2007). This idea was further developed and tested in the Task pre-load study.

4.3.3 Mismatch

Another explanation for reduced driver performance may be found in a mismatch between real mental demand and the effort the driver puts into the task. Thus, the effort invested by the driver does not reflect the demand in reality. According to State Control Theory (Hockey, 1986), central executive mechanisms compare the current cognitive state with a required or target state. Whenever there is a mismatch between these two states, the energetical construct of effort can be involved in actively changing the current state towards the target state. Hockey calls such a manipulation “state management”. However, if drivers misinterpret the required and target states they will consequently not adapt their effort. Thus, the problem is not that the level is too high or low but rather that it has been adjusted to the wrong level.

In the Mismatch study workload was divided into a three level construct influenced by De Waard (1996) and Kantowitz (1987), that may be aligned or separated: Real
World Complexity (RC), Subjective Complexity (SC) and Invested Effort (IE). If any of these levels does not align, there may be a risk for reduced safety and or a negative experience for the driver (see figure 8).

The reason for decreased performance may not be that the driver has reached the upper limit of his or her performance but rather that there is a mismatch between the three levels. A mismatch may result in either reduced safety and/or reduced user experience. For instance, if the driver puts less effort into the task than required by the real world complexity, performance may be reduced. On the other hand, if the driver puts more effort into the task than needed because the subjective complexity is high, the driver will both have a worse experience and eventually also become fatigued which can in the long run affect safety.

Figure 8. Examples of possible mismatches. Mismatch scenario number 0 represents normal driving, numbers 4 and 6 represent single mismatch scenarios and numbers 7 and 11 represent double mismatch scenarios.

4.3.4 Summary of mental workload
It may be suggested that an ADI should support the driver in reducing too high mental demand and increasing too low mental demand and, if there are mismatches, try to eliminate these by information.

4.4 Situation awareness
Situation awareness (SA) is a concept that was developed by Endsley (1994) and consists of a) perception of the elements in the environment, b) comprehension of the current situation and c) projection of future status. In a review of commercial aviation accidents, 88% of those caused by human error were found to be due to problems with situation awareness (Endsley, 1994). That is, in the majority of cases, people do not make bad decisions or execute their actions poorly; they misunderstand the situation they are in. Thus, the best way to support human performance is to better support the development of high levels of situation awareness (Endsley, Bolte and Jones, 2003).
The concept of SA has been criticized and an important issue in SA is that it only considers conscious (we are aware) processes. For instance, the taxonomy of Tricks and Enns (2009) and the attention selection model by Engström (2011) show that attention selection can also be automatic and therefore unaware to the driver.

Still, SA contains several useful ideas, for instance that people make projections of future events based on their actual mental model of the situation and act instead of react.

4.5 Context
There are several hundred warnings, information tell-tales and text messages in a modern car. There are also gauges, trip computers, navigation systems and head up displays, and the number of functions is growing. Some of the information is provided by just looking out of the car and some are provided by the road authority through road signs. However, a very small portion of the information needs to be there in all contexts. One solution may be ADI.

There is not much research about the information needed in different contexts. However, in the Context study it is concluded that a driver needs and/or wants different information in different contexts. For instance, a driver may not need a traditional speedometer when planning a trip or when the car is parked in the garage. Information about engine temperature is of little use when the engine is shut off. Knowledge about what is going on half a meter behind the car is of limited use while driving 120 km/h on a highway.

Other information may even be inappropriate for specific situations. Complex, visual or cognitively distracting feedback information about how to drive more safely or more environmentally friendly may be more suitable before or after driving. Likewise, distance alert or gear change advisors are obviously more useful while driving.

Interestingly, in the Context study it was shown that there is sometimes a discrepancy in drivers’ opinions about what should be presented by the in-car technology and/or what should be the driver’s responsibility. There is varying consensus over different functions in different contexts. This may, although this is not confirmed, be a result of different locus of control in the participant (Rudin-Brown & Noy, 2002) where externals rely on and accept technology more and internals less.

4.6 Traffic situation
The traffic situation may also affect how the driver should be supported. The relationship between crash rate and hourly traffic flow on an interurban highway follows a U-shaped curve where the incidence rates are highest when traffic is lightest and are lowest when traffic flows at a rate of 1000–1500 vehicles per hour (Martin,
2002). For heavier traffic flows, crash incidence rates again increase steadily as traffic increases (Martin, 2002).

Martin’s (2002) explanation of the high crash rate during low density is that the driver’s demand is reduced when the traffic volume is light on motorways, which causes an overcompensation in speed that reduces safety. This explanation is similar to the MART by Young and Stanton (2002) that explains a decrement in performance by underload and by Heslop et al. (2010) that concluded that some people tend to take action against boredom by driving faster.

4.7 Driver state

Just as in the case of personal trait, driver state is also often an explanation for accidents. The difference between a driver’s state and a driver’s personality trait is that the driver’s state or condition can vary heavily from one hour to another while the latter is more or less a stationary condition.

One common state that used to be described as a cause of accidents is sleepiness. Sleepiness refers to “a situation when the driver has to make efforts to stay awake while driving” (Anund, Kecklund and Peters, 2004). The statistics on how many accidents are caused by drivers falling asleep range between 1 and 3 percent (Larsson & Anund, 2002; Lisper, 1977; Stutts, Wilkins, Osberg & Vaughn, 2003) and 10 and 30 per cent (Connor, Whitlock, Norton & Jackson, 2001; Horne & Reyner, 1995; Maycock, 1997). Regardless of which figure is correct, many people are killed every year due to sleepiness.

A large portion of the sleepiness research has to date been on the reasons for and the detection of sleepiness, and it has been found that driving parameters such as Steering Wheel Reversal Rate (SWRR) and speed variability (Sandberg, 2008), and blink behaviour such as pupillary diameter (Fors et al. 2011), can be used to indicate sleepiness.

Most experts believe that the only truly effective countermeasure for sleepiness is to immediately stop driving and get some sleep. According to Nguyen, Jauregui & Dinges (1998), for instance, letting someone else drive for a few hours while you sleep before driving again and taking a 30 to 45 minute nap is the behaviour that will most surely result in increased alertness in a sleepy driver.

In the Drowsiness study it was concluded that drivers do take actions to avoid sleepiness. Unfortunately, these actions are other than what experts believe is helpful. Anund, Kecklund, Peters & Åkerstedt (2008) found that the most common countermeasures were to stop to take a walk (54%), to turn on the radio/stereo (52%), to open a window (47%), to drink coffee (45%) and to ask passengers to engage in conversation (35%). These figures are in large confirmed in the Drowsiness study;
only 3 per cent actually stopped and took a nap. Thus, there is a huge mismatch between researchers’ belief and common drivers’ action.

The reason for not stopping and taking a nap may be that drivers either may not feel sleepy or may not recognize or confess to themselves their feelings of sleepiness (Stutts, Wilkins & Vaughn, 1999). However, other research has shown that most drivers understand that they are tired but that they are not always able to identify when they will fall asleep (Anund, 2009). Another likely factor is that the motivation to reach the goal is more important than driving safely (Stutts, Wilkins & Vaughn, 1999). In addition to this, the Drowsiness study indicated that the drivers are biased by a belief that their methods for avoiding sleepiness actually work.

4.8 Drivers’ Age and Gender

There are several common misunderstandings regarding elderly persons in traffic. First of all, the largest problem for the elderly may not be safety; it may rather be limitations in mobility, due to self-chosen compensatory restrictions (Evans, 1991; Charlton et al., 2006). Older people have better self-assessments than younger drivers and are better able to adapt their driving by avoiding too demanding driving conditions such as high traffic density, poor visibility, bad road conditions etc. The major portion of the explanation of their higher rates of injury and fatalities seems instead to be the greater physical fragility of older drivers (Evans, 1991).

Nevertheless, the different types of accidents are different in different ages. Older drivers are “under-represented” in accidents, such as single accidents or collisions due to risky behaviour, but they show an increase of intersection accidents (Blomqvist, Siren & Davidse, 2004). One explanation, which was confirmed in the Personality study, for the reduced risk taking behaviour among older drivers is that there is a negative correlation between sensation seeking score and age (Zuckerman, 1994).

The reason for elderly’s problems in intersections may be that the demand on the driver is set by the intersection design, by the pace of the other road users (Blomqvist, Siren & Davidse, 2004) and by higher task load in the intersections (Gsalter & Fastenmeier, 2010). Thus older drivers may be required to act under a time pressure that exceeds their own capability, while it is easier to control the vehicle at their own pace elsewhere (Blomqvist, Siren & Davidse, 2004).

Furthermore, younger drivers plan further ahead and look more at moving objects in contrast to older drivers who look straight forward more often and focus on static markings. Older drivers seem to be more concerned about their position and they try to be in the right place and not to disturb other drivers (Ducic & Broberg, 2012).

There are also differences between genders. It has been reported that young to middle age drivers and male drivers have the highest risk frequency and the lowest perceived
personal risk while driving sleepy (Obst, Armstrong, Smith and Banks, 2011; Glendon, Dom, Davies, Matthew and Taylor, 1996). This also appears to be applicable to risky behaviour in general (Rhodes & Pivik, 2011). González-Iglesias, Gómez-Fraguela & Luengo-Martín (2012) reported that males have a greater number of penalties and accidents.

4.9 Time factor

Some of the input factors change more or less slowly and some of the input factors discussed above may never change (See table 4). The pace of change has implications for the technical solution. Slowly changing conditions may require long term storage of data, even longer than the lifetime of the vehicle, while quickly changing conditions need short range sensors and no storage of data. Some of these slowly or never changing input factors should perhaps not be changed automatically. In these particular cases may a manual setting perhaps be more suitable.

<table>
<thead>
<tr>
<th>Change pace</th>
<th>Input factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>slow</td>
<td>Personality trait, age, gender*</td>
</tr>
<tr>
<td>intermediate</td>
<td>Level of control, motives, skill and historical data, driver state</td>
</tr>
<tr>
<td>quick</td>
<td>Risk, mental workload, context, traffic situation</td>
</tr>
</tbody>
</table>

Table 4. The change pace (*Gender may never change)

4.10 Other areas to adapt to?

There are probably several other factors to adapt to, and some of them are discussed in the section on future research. However, there is always a risk that some factors have been left untreated un-purposely. Still, hopefully most of the important input factors are included in the thesis.

4.11 Summary of aspects to adapt to

The input factors that may initiate a change in the ADI system were presented and analysed in an ADI context. Drivers can be supported on strategic, tactical and operational levels of control but it may also be possible to affect higher motives and norms.

Personality can affect driving performance but can also be affected by design. For instance, an internal LoC may predict low trust in technology, such as automation.

An important area from a safety perspective is the driver’s state. ADI can possibly support the driver throughout the development of, for instance, sleepiness.

ADI can also change when skills develop. Information early in the development of skill may look different from information presented to experienced drivers.
Too low a workload can be managed by adding task demand and too high a workload by reducing task demand. Mismatches between demand and invested effort can be managed with information.

The context and the driving situation may heavily influence ADI. The information needed in rush hour and in a complex context is different from low density traffic and contexts with low complexity.

Age and gender should also change the content of ADI, even if these parameters change slowly or never.

To summarize, when designing an ADI, all of the mentioned areas could influence the appearance of the information presented to help users to better reach their goals.
5 Negative aspects of an adaptive system (RQ3)

This section discusses RQ3, which has to do with the possible issues regarding ADI.

When planning the project it was early concluded that an adaptive driving information system was associated with problems such as skill reduction, mental workload, driver state, trait, historical behavioural data, driver performance etc. Similar problems also seemed to appear in automation, an already well-researched field. It was therefore natural to continue on this track.

Automation induced issues are hard to foresee (Bainbridge, 1983) and must therefore be handled with care. This section will try to identify these issues and explain why.

However, this section will also discuss automation on a somewhat higher level than only for ADI. The reason is that there is growing interest not only in the automation of driving information but also in more complete automation, such as in autonomously driven vehicles.

5.1 Introduction to automation induced issues

Much has been written about the difficulties of automation. Bainbridge (1983) concluded that automation can have some unwanted side effects and may even create new problems. Stanton and Young (2000) discussed driving automation and raised issues such as trust, mental workload, locus of control, driver stress and mental representation. In Sarter, Woods and Billing’s (1997) article about automation surprises, it is concluded that the main question is rarely what can be automated but rather what should be automated to support human operators. Automation must proceed from technology focused to a user centred approach to be effective and safe. Sarter and Woods (1995) illustrated the mode error problem by giving their article a title that is a common question in the use of automated systems: “How in the world did we ever get into that mode?” These automation induced issues are discussed in this section.

It is too early to say whether any or which of the automation induced surprises described below will occur during either ADI or automated driving. The surprises have mainly occurred in the process industry and aviation, where automation is common. However, a cautious approach where the issues in other domains are discussed in a road vehicle context may never be wrong.

5.2 Function allocation

Automation may be controlled within the continuum between manual and automatic (see e.g. Parasuraman and Riley, 1997). In manual control, the human must take all the decisions and actions and the “system” does not offer any assistance. In the intermediate levels of automation, the automated system may suggest or give advice
but does not act without approval. At higher levels of automation, the “system” decides everything and ignores the driver.

Classic questions in automation are “who is doing what?” and “what should the driver do and what should the car do?” Long MABA-MABA lists (Men Are Best At – Machines Are Best At) have been created throughout history (see for instance: Fitts, 1951). Most lists have been heavily criticized, and even Fitts (1962) admitted that he “fell into the trap of trying to make a list” and that this effort was “trivial and somewhat misleading”. Dekker and Woods (2002) argue that substitution based function allocation methods (such as MABA-MABA lists) cannot improve human-automation coordination. Instead, they propose that the more interesting question about human-automation coordination is “how do we make them get along together”.

Furthermore, the responsibility for the most basic functions in the driving task, lateral or longitudinal control, is in automation moved from the sharp end, the driver, to the blunt end, designers and organization that are not even in the car (Hollnagel, Woods and Leveson, 2007). This expands the sociotechnical system to also include the manufacturers to a much larger extent and increases the complexity of the sociotechnical system.

5.3 Mode confusion
Mode confusion occurs when devices have more than one mode of operation and the action appropriate for one mode has different meanings in other modes. Mode confusion is predictable any time equipment is designed to have more possible actions than it has controls or displays which results in the controls having to do “double duty” (Norman, 1988).

If information in ADI changes without the influence of the driver, the display then has more than one “duty” and may therefore also end up asking the same question as the title of Sarter and Woods (1995) article “How in the world did we ever get into that mode”.

Similarly, if the driving task is automated, drivers may for instance believe that the car has both lateral and longitudinal control while it may in fact only have longitudinal control. The effect of such a mode error has of course much worse consequences than ADI does.

5.4 Over and under trust
Belief and disbelief in both oneself and automation have an impact on the usage of automation (Lee & Moray, 1992, Muir, 1987) and according to Muir and Moray (1996), the level of feedback collected from an automated system by an operator is directly related to the degree of trust the operator has in it to perform without errors.
Thus, operators will use automation when trust is higher than self-confidence but will switch to manual control in the opposite case.

Too much confidence creates another issue. When trust has developed and an automatic system has become accepted, there is a possible risk that users will become too trusting in the automation. This can lead to a reduced willingness to evaluate or monitor the automated activities, a situation that has been described as automation induced "complacency" (Parasuraman, Molloy and Singh, 1993; Stanton and Young, 2000).

Trust can however be managed by design. Beller, Heesen and Vollrath (2013) and Seppelt and Lee (2007) state that continuous information about automation is preferable compared to providing warnings and that information about automation increases trust and acceptance. On the other hand, increased trust in a system as untrustworthy may be something negative.

The goal must, instead of always increasing trust, be to better help the driver to calibrate trust and thereby put the correct level of effort into the task: more if automation is close to its limits of performance and less if it is not.

5.5 Skill degeneration or poor skill development
A driver’s behaviour may never reach the skill based level if it is never or seldom practiced, and driving skills may even decline in the presence of long periods of automation (Wickens and Hollands, 1999).

Driving is a highly visual task (Peacock, Karwowski, 1993) and it has been estimated that over 90% of the information received by the driver is visual (Sabey & Staughton, 1975). Even if it is less or more than that, vision has been ranked as the dominant source of information for the driver (Wierville, 1993).

When designing display content for a driving information system it is therefore necessary to understand visual behaviour. For instance, people tend to fixate longer on areas with high information content. Scanning and sampling strategies and fixation dwell times are also governed by the difficulty of information extraction. Displays that are less readable or contain denser information will be fixated longer (Wickens and Hollands, 1999).

In addition, expertise affects the difficulty of information extraction and, therefore, fixation dwell times. For instance, a novice pilot’s dwelling on information rich attitude direction indicators is nearly two times longer than an expert’s (Wickens and Hollands, 1999).
An adaptive interface may possibly reduce clutter since only the most necessary and useful information for the task is available. On the other hand, an adaptive change between, for instance, several different modes of information could reduce the likelihood of developing expertise in comparison with the case in which the information never or rarely changes. This is a strong reason to keep the number of modes low for the driver and it is probably a fastidious task to get the balance correct.

5.6 Workload in automation

One important notion behind automation is that it should help to reduce mental workload. However, it is indicated that this does not necessarily happen. In fact, Wiener (1989) claimed that the introduction of automation sometimes even increases workload. He cautioned that automated systems may often function well under periods of low workload and become a burden during high workload periods. Hancock and Krueger (2010) called this phenomenon “Hours of Boredom, Moments of Terror”.

The explanation may be that automating a function increases the number of decisions from one to three that a human operator must make in diagnosing a system malfunction (Wickens and Hollands, 1999): for instance, if an automated system monitors the doors of a car to ensure that they are closed during the trip. In the occurrence of a failure indication, the driver must decide whether it reflects a dangerous condition, a failure in the automated monitor or a malfunction in the display indicator of the automated system.

For a dialogue manager in a manual or low level of automation control, the driver is in command of what is shown and therefore nothing, or at least less expected events, happens. For instance, if the driver wants to hinder some information from being shown in order to reduce mental workload in a difficult situation, he or she must first interact with the information system and tell it not to present this information. The driver would understand why some information was not shown, but the interaction would of course add an even greater workload.

5.7 Situation awareness - Out of the loop performance problem

Regardless of whether the driver’s task is to choose to intervene, detect a system event, or accept or reject the actions of an automated system, the driver is removed from direct, real-time control of the system (Kaber and Endsley, 1997). Drivers are out of the control loop, and this may lead to decreases in situation awareness (Sarter & Woods, 1995) and thereby reduced system performance. For instance, Merat and Jamson (2009) found that drivers’ anticipation of critical events was much slower in an automated driving condition compared to when driving was manual.
5.8 Technology acceptance

According to Davis’ (1989) technology acceptance model (TAM) the use of technology is affected by perceived usefulness and perceived ease of use as well as the attitude toward using and intention to use the system. As mentioned earlier, LoC is one of the factors that predicts technology acceptance.

5.9 Summary of automation induced issues

The recovering of control, user experience and acceptance of an ADI system are most likely strongly dependent on how well automation induced issues are dealt with. If the work split between automated and human agents is solved, the modes are few and differentiated, and drivers’ trust is calibrated with the system performance, skill maintained and technology accepted, an ADI may function well.

Figure 9. What affects recovering control
6 How can adaption be carried out? (RQ4)

Chapter four identified several potential input factors and the challenges were described. Chapter five highlighted a few issues to avoid in automation contexts. The present chapter is a discussion and an attempt to explain how an ADI can be carried out based on the input factors and the ways identified to avoid automation induced issues in order to support the goals defined in Chapter 3.

6.1 Adapt to level of control

ADI offers the opportunity to support the driver in the different levels of control by change information needed for the driver’s particular level. The Context study resulted in and explains an easily understood “zoom lens” metaphor of which level of control is needed (see figure 10). Before, when planning the trip, the driver zooms out to make strategic decisions about the trip. In the parking area, the driver zooms into the closest proximity of the vehicle. Then, on the highway, the driver again zooms out. What is going on next to the car is of less importance. When the driver approaches an intersection, the tactical positioning is more important and the driver zooms in again, but not to the closest proximity.

<table>
<thead>
<tr>
<th>Before/After (Strategic)</th>
<th>Parking (Operational)</th>
<th>Straight Highway (Tactical/Strategic)</th>
<th>Intersection (Operational/Tactical)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Parking" /></td>
<td><img src="image3" alt="Highway" /></td>
<td><img src="image4" alt="Intersection" /></td>
</tr>
</tbody>
</table>

*Figure 10.* Zoom lens metaphor about how drivers reason and how an interface could be realized

This can also be described in terms of level of abstraction (Feigh, Dorneich and Hayes, 2012). Choosing the correct level of abstraction for the main functional relationships is often the aim of ecological interface (Burns & Hajdukiewicz, 2004) design in which Cognitive work Analysis belongs. This metaphor can be used as a heuristic when deciding which function should be available when.

In fact, as a result of this project, this has been partly implemented in Volvo Cars. Figure 11 a and b show the car’s instrument while parked. The interior is shown and how many persons that are belted. Then, when the car starts to move, a view with a car and its surroundings is shown. Tactical information, such as distance settings for ACC, distance alert and how well the lines can be seen by the Lane Keeping Aid (LKA) camera, is shown.
The top level in Hattakka et al.’s (1999) taxonomy indicates that drivers’ norms or “goals for life” affect the lower levels, such as strategic decisions etc. Adapting driver information to a driver’s goal may be a way to improve performance, and it seems to be possible to develop a system that will encourage drivers to drive in a safer and greener manner through on-board advice and post-drive feedback (Young, Birrell, & Stanton, 2011).

Nevertheless, countermeasures intended to change poor behaviour such as speeding may be directed to the “goals for life” level and to one or more of the following factors: attitudes, subjective norms or perceptions of behavioural control (Ajzen & Fishbein, 1980) according to the theory of reasoned action.

Here, new technology such as social media can offer a solution. Results show that normative messages are presented and, the more similar the situational circumstances are, the more efficient is the appeal to change behaviour. For instance, appeals using descriptive norms (e.g. “the majority of guests in this hotel room reuse their towels”) are more efficient than a traditional appeal that focused solely on environmental protection (Goldstein, Cialdini and Griskevicius, 2008). Thus, perhaps the message “your Facebook friends have an average fuel consumption of 5 l/100 km at this road” would change a driver’s behaviour.

6.2 Adapt to risk

One implication of Summala’s (2007) and Ljung’s (2012) thoughts may be that it is beneficial to communicate to the driver how close to the safe zone boundary the Driver Vehicle Environment (DVE) system is, both in order to avoid accidents but also to avoid discomfort, which can be regarded as one of the purposes of driver information (enjoyable). A system that does not show its limit of performance to the driver may put the driver in a stressful and thereby inconvenient situation. For instance, an adaptive cruise control system that does not tell the driver that it only works above 30 km/h or under a specified deceleration may require the driver to intervene more quickly than expected which, of course, creates discomfort.

A visualization of how close a driver is to the safety boundary can be executed in many different ways. For instance, Beller, et al. (2013) show that a vehicle with an
uncertainty symbol (the more uncertain, the closer to the comfort zone boundary) received higher trust ratings, increased acceptance, improved situation awareness and improved knowledge of the system fallibility of an Adaptive Cruise Control (ACC) System.

Furthermore, the *Uncertainty* study indicates that drivers who were informed about the “car certainty” (for instance how well the road markings were perceived by cameras) were better prepared to switch to manual control if needed (see the left side of figure 12). Simultaneously, the test group better calibrated their trust in the system to a level which was more in line with system performance.

**Figure 12.** How vehicle certainty was displayed to the driver in the *Uncertainty* study (the right side). The middle part is confidential and therefore censored. The effect of the right side and both in combination is still to be investigated.

After the work in the *Uncertainty* study it was also discussed what a design would look like where also other agents, such as the driver, show certainty in automation (see the right side of figure 12). This level of certainty may be similar or equal to how aware, alert, attentive or prepared the driver is to intervene. This will be further discussed in the chapter on future research.

### 6.3 Adapt to personality trait

High sensation seekers, type A personalities, drivers with an external locus of control, extraverts or easily bored drivers are more likely than others to end up in an accident (c.f. Jonah, 1997). Still, there are few examples of how to manage this problem. The lack of a solution seems to be at least twofold to be practically useful in road vehicles: *identification* and *design*. It is of course possible to take a single or to find a pattern of poor driving behaviours and counteract them separately, but there is already some
research on how to design for different personalities. In this thesis it is therefore suggested that personality trait can be used as a common denominator regarding identification and design.

6.3.1 Identification

One reason why it is challenging to design for personalities may be that it is difficult to distinguish between different personalities without asking people to fill in questionnaires or forms, for instance when applying for a driving licence, in the car purchase situation or when searching for an appropriate insurance policy. The common acceptance of the use of personality tests to screen drivers and how the results of the test should be applied remain to be discussed (Verwey and Zaidel, 2000).

However, used in a manner acceptable to the driver, there may be a short cut. Boyse (1999) found a correlation between driving characteristics (speed and distance keeping) and personality type A and suggested that information about personality can be used to design more effective driving safety systems and target them to populations of risky drivers in particular. Would it be possible to, and do manufacturers want to, by driving characteristics such as lane keeping performance, speed choice, distance keeping performance or braking behaviour, identify and thereafter adapt driver information to the specific personality?

The Personality study investigated the correlation between sensor data and the score on a sensation seeking scale. Several of the sensor data correlated with the personality trait of sensation seeking. The study also revealed that, in a near future, it would be possible to at some level predict sensation seeking personalities by analysing driving data.

6.3.2 Design

Thus, if it were possible to distinguish between different personalities without filling in questionnaires, what would then be done? At present, legislation, disclaimers, blocking and banning are common countermeasures to avoid poor driver behaviour, such as speeding. Unfortunately, these methods seem to be inefficient and there are even examples of their being counterproductive. For instance, the number of accidents increased by between 1 and 9% when a texting (SMS) ban was introduced (Holbrook, 2010) in some states in the USA. The most likely reason is that those who anyway text hold their phone lower to avoid fines, which increases the eye time off road which in turn increases the risk of accidents.

Another reason why banning and blocking etc. are inefficient is that for instance sensation seekers are willing to take physical, social, legal and financial risks for the sake of such an experience (Zuckerman, 1994). Furthermore, Brehm’s (1966)
reactance theory suggests that, when people perceive that their freedom is restricted, a state of psychological reactance will be stimulated, which may result in disobedient attitudes and behaviours. Psychological reactance is especially common in youths, who are beginning to establish their personal independence.

If we manage to identify accident prone drivers, it seems more appropriate to adapt to their behaviour rather than obstruct them. A few examples from research follow of how ADI can reduce negative behaviour among accident prone drivers:

- Tailor safety campaigns or shape information for sensation seekers (Ulleberg and Rundmo, 2003). Campaigns may be placed in the vehicle but preferably in off-board systems where the driver can look without being distracted.
- Systems can be designed to increase trust and acceptance for drivers with internal LoC and better calibrate trust for externals to avoid behaviour adaptation. For instance, the Uncertainty study showed that drivers (simulated driving) who were shown sensor uncertainty representation took control of their autonomous vehicle faster when needed and had better calibrated their trust in the automatic driving system.
- If the driver is an introvert, reduce demand by blocking information such as suggested by Piechulla, Maysr, Gehrke and König (2003); if the driver is an extrovert, stimulate the driver with an interactive cognitive task in monotonous situations as is suggested by Gershona, Ronen, Oron-Gilad and Shinar (2009).
- Designers can start to develop systems (e.g. entertainment) that stimulate but do not visually distract for those personality traits with a normally low arousal level, such as extraverts or those who are susceptible to boredom. This may very well be possible due to technology such as voice recognition and speech synthesis.
- Thiffault and Bergeron (2003) suggest that more monotonous roads should be avoided by high sensation seekers or extraverts. One solution may be that navigation systems suggest different routes depending on personality.
- The adaptive driver system suggests when it is appropriate to engage in a stimulating task to maintain performance, such as along monotonous roads.
- Replace a risky behaviour with a non-risky but still equally stimulating task (Roberti, 2004). For instance, in the Drowsiness study it is suggested that an interesting and challenging quiz can substitute more hazardous behaviour such as speeding. Unfortunately, the effect of such an approach has not yet been investigated.
- Adapt the type of communication to personality trait (Palmgreen et al., 1991). For instance, messages targeted to the sensation seeking level have been shown to be efficient. Studies show that persons who are high sensation seekers tolerate or even need stronger messages to attract and maintain their attention (Donohew,
Palmgreen and Duncan, 1980) and that the messages should contain a component of surprise (Banerjee, Greene and Yanovitzky 2011).

6.3.3 Summary of adapt to personality trait
Some personality traits are found to be accident prone or affected by design. It seems possible to identify some of these traits by an analysis of driving characteristics data and thereafter design the ADI accordingly.

6.4 Adapt to skill and historical data
Drivers’ needs seem to change over time, from a need of knowledge- and rule based and cognitive support in the beginning of the learning process to support avoiding unexpected events when skill has been developed. The implications may be that driving information, after some time, becomes less knowledge based; the driver knows how long the trip takes and which lane should be used. Instead, the driver information focuses on supporting skill based behaviour and change wrong schemata.

As the mental demand gets lower throughout the development of skill (skill based behaviour is highly automated) (Rasmussen, 1986) it may even be that driver information should support the driver in staying focused and alert by increasing task demand.

In the Team player study the team player approach is applied to adaptive (automated) driving information. The team player approach is in short that the agents within automation show each other common goals, show intention, share representation of the problem state, they negotiate, show its limits of performance and give each other feedback (Klein, Woods, Bradshaw, 2004; Christoffersen and Woods, 2004) to avoid automation induced issues of which one is skill degeneration.

The experts in the Team player study experienced that the approach described by Klein (2004) and Christoffersen and Woods (2004) rather described agents before they reach a skilled based behaviour or become team players than being team players. Real team players do not need to show intention, reasoning etcetera. The main issue is the journey to become team players, a procedure that was called “team building”.

One of the solutions discussed in the study was to offer a separate view that could be used to develop skill in understanding how the system works. More about this separate view later (Chapter 6.11.3).
6.5 Adapt to the human information process

Much has been done to support the information process on the grounds of its strong influence on engineering psychology. For instance, in many modern cars, the sensor stage is enhanced by night vision systems, radio volume is increased when ambient noise increases due to speed and different warning systems such as for instance Forward Collision Warning systems (FCW) act as a salient substitute for the reality outside the car. A great deal of effort is also put into how to make drivers understand the information to reduce the mental workload imposed on the driver (Cognition).

The first step, sense, is dealt with in the chapter about age. Perception and cognition are handled mainly in the next section about mental workload. Thus, the discussions regarding the human information process are distributed throughout the thesis.

6.6 Adapt to drivers’ mental workload

ADI can support the driver in optimizing mental workload in at least three different ways: reduce too high mental workload, increase too low workload and try to eliminate mismatches between Real World Complexity and Invested Effort, which was one of the results in the Mismatch study.

6.6.1 Reduce too high a mental workload

A great deal of research has been performed to reduce mental workload (c.f. deWaard, 1999). Studies in this thesis have not dealt with too high a mental workload but rather with when the mental workload is too low. Nevertheless, a few of the strategies that can possibly reduce high workload are worth mentioning since even ordinary levels of workload can be too high when drivers have been exposed to a too low demand for some time (Young and Stanton, 2002).

According to Woods and Hollnagel (2006), it is possible to reduce the mental workload during high demand in four different ways: shed load, shift work in time to lower workload periods, recruit more resources or carry out all components but do each less thoroughly. ADI would be able to do three of these. The fourth (do the task less thoroughly) is not recommended.

**Shed load**

It is possible to completely block information that is not useful to the driver in a particular situation. For instance, the results in the Context study may be useful for deciding what information is needed or wanted in each context.

**Shift work in time to lower workload periods**

Workload could either be moved forward in time if the information is useful in the future or back in time if it is possible to predict too high a mental workload.
Piechulla, Mayser, Gehrke and König (2003) proposed a system that reduces mental workload when an incoming phone call, instead of being transferred to the driver, was redirected to a “mailbox” whenever the workload estimation exceeded a defined threshold. A practical implementation of this is Volvo Cars’ Intelligent Driver Information System (IDIS) (Broström et al., 2006), where the workload is calculated by a set of rules and, if the workload value is high, some information is blocked or postponed.

There is also a possibility to provide the driver with information about the future during periods of low workload (see figure 13). In particular, it seems that information about the future (feed forward) has great potential. For instance, a study by Alm and Nilsson (2000) showed strong positive effects of feed forward by Incident Warning Systems (IWS). Another example would be to give the driver information early, during low demand, about a future complex intersection instead of giving the information just before the intersection, as most navigation systems do today.

![Figure 13. Illustration of how the performance level may possibly be increased by information/priming/pre-loading](image)

This approach may have at least two but perhaps even three benefits:

1) Support *situation awareness* (projection of future status). The driver is prepared when entering a complex driving situation and can concentrate on the operational (for instance, avoiding pedestrians) or *tactical* task (such as choosing lane), rather than the *strategic* (where to go).

2) The driver's performance level is higher according to the Malleable Attention Resource Theory (MART), which implies that the resource pool shrinks to accommodate the reduction of demand in low demand tasks and consequently increases due to mental pre-loading (Young and Stanton, 2002).

3) A potential third benefit is to present information in order to affect the selection of attention (Engström, Markkula and Victor, 2009), for instance, if the driver’s attention is governed by an imperfect schemata over hazards.
Recruit more resources
More resources could be achieved by an automation of a driver’s tasks, for instance steering or braking. Today, some of the Advanced Driver Assistance Systems (ADAS) support the driver when the workload is or has been too high, performance has been reduced which have led to an incident.

ADI is also of course a way to recruit more resources in comparison with a manual switch between different modes of information. This is for instance described in a paper by Hameed and Sarter (2009) and will be discussed further later.

Do all components but do each less thoroughly
The relation between driver performance and workload is described for instance in a model by Mulder (1986). If the workload is too high, performance degrades. A strategy not recommended for the driver to reduce mental workload to a handy level may therefore be to do things less thoroughly, for instance, to look less for obstacles or hazards.

Change modality
In addition to the four methods of dealing with workload presented by Woods and Hollnagel (2006), according to MRT it would also speed up processing to redundantly code information across modalities (Wickens and Hollands, 1999). Therefore, one way of reducing mental workload is to give drivers information in other modalities than those that are used for driving. However, as mentioned earlier, it seems better to assist the visual interaction rather than replace it (Rydström, 2009).

6.6.2 Increase mental workload during low demand
Increased mental workload during too low a demand may also be beneficial for a driver’s performance. In fact, some drivers already take actions against too low a mental demand. For instance, as mentioned in the section about personality traits, drivers that become easily bored drive faster than non-easily bored (Heslop et al., 2010). Instead, an ADI may have the opportunity to supply alternatives to speeding or other activities that could be categorized as poor behaviour.

It seems appropriate to provide non-visually distracting but cognitively stimulating tasks while driving if the task has too low mental demand and to reduce mental demand if it is too high in order to maintain driver performance (Nachreiner, 1995).

In the Pre-load study a technique is described to, in a low visually distracting way, increase drivers’ mental workload in order to optimize performance. The drivers were asked questions aloud about landmarks commonly used in navigational tasks along the monotonous route, and the participants verbally answered the questions. The idea was that the added task should make the driver more active but also stimulated cognitively by the memory task and thus make them better navigators. The results were
unambiguous and showed an increased mental workload but no improvement in response time in a brake event. The reason for unambiguity may be that the response time in highly automated tasks such as keeping a distance to a vehicle ahead is not affected by cognitive load (Tricks & Enns, 2009).

Still, several other studies show that cognitive stimulation can affect performance positively during low demanding conditions (Gershona, et al. 2009; Verwey and Zaidel, 1999; Atchley and Chan, 2010).

Furthermore, a naturalistic study by Olson (2010) showed that taking part in a phone conversation or controlling the radio channels could even slightly decrease the risk for accidents during monotonous long trips and, in a very novel naturalistic driving study by Victor, et al. (2014), “talking/ listening on cell phone” even has an odds ratio of only 0.1 representing a large reduction in risk. The explanation in Victor et al. (2014) is a reduced risk of falling asleep and/or that phone conversations (and other cognitively loading tasks) induce a concentration of gaze towards the road centre, which increases the chances that the eyes are on the forward path when a lead vehicle brakes.

The pre-load technique used in the Pre-load task study was later further developed into an Iphone app (see figure 14). The app still verbally asked questions about things the driver should have seen along the road. However, to make it even more cognitively stimulating and interesting, questions were also asked about the region they were driving in. The app only poses questions on monotonous road sections, and Bluetooth is used in combination with a built-in hands free system. The driver responded verbally or by pushing very large buttons on the screen. From an ADI perspective, this type of app or other cognitively stimulating activities may serve as an alternative to “talk/listen on cell phone” and be suggested or triggered by low demand, monotony and perhaps also depending on drivers’ individual mental workload.
6.6.3 Reduce mismatches

In the *Mismatch* study mental workload was divided into a three level construct that may be aligned or separated. If any of these levels does not align, there may be a risk for reduced safety and or a negative experience for the driver.

The study’s results show 12 mismatch scenarios that can be used to analyse safety and user experience. Using the framework’s descriptions of how and why mismatches occur can be developed, implications for design of an ADI can be defined.

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**Figure 14.** Test driving an Iphone application that intends to increase mental demand during monotony

**Figure 15.** Ways ADI can support different strategies to cope with different levels of task difficulty
6.6.4 Summary of Adapt to drivers' mental workload
An ADI can deal with mental workload in three ways, described in figure 15 above: reduce it when it is too high, increase it when it is too low and minimize the possibility for mismatches to occur.

6.7 Adapt to context
The Context Function Matrix (CFM) from the Context study is shown in figure 17. CFM may be used when designing context adaptive systems. Functions that are less useful give display space to more useful ones. However, a warning is required. Consensus is low for some of the functions. These functions may instead be activated manually or with a lower level of automation.

![Figure 16. Context Function Matrix (CFM). The different contexts are located on the horizontal axis and the different abstract functions on the vertical.](image)

6.8 Adapt to traffic situation
The solution proposed by Martin (2002) is to introduce a safety campaign directed to motorway users to influence their behaviour in the particular driving conditions. An ADI could of course also inform about increased risks while driving in different conditions but should perhaps also provide a means to avoid the cause, the reduced mental demand, by, for instance, systems such as in the previous section about workload.

6.9 Adapt to driver state
There are few examples or guidelines about how to adapt information to driver state. Anund (2009) proposed a support strategy that may help the driver through the development of sleepiness.

The driver must first identify the feeling of sleepiness. Secondly, the driver must be motivated to take corrective actions, and have knowledge about effective and lasting
countermeasures. Finally, the driving context should permit the driver to act according to an effective strategy.

In the first phase, the ADI system may better indicate sleepiness if knowledge about the individual has been obtained. If a driver’s behaviour on previous occasions has shown signs of sleepiness early, this knowledge can be used to trigger countermeasures earlier. Another example would be to use knowledge about personality trait. For instance, a driver with an extrovert personality trait may get stimulation earlier.

In the second phase, it is more likely that a person with external LoC disregards support information and continues to drive due to a lower trust in the technology (Rudin-Brown & Noy, 2002). The *Uncertainty* study explains a possible way to better calibrate trust in safety systems.

In the final phase, it would be possible to provide, suggest and support different countermeasures such as when and where it is possible to rest or take a nap. Perhaps a future driver alert system can suggest drowsy drivers a route to an appropriate parking place or coffee machine.

However, as mentioned earlier, there also may be an additional solution for the third phase. The study by Gershona et al. (2009) demonstrated that a motivating cognitive stimulation while driving has the potential to suppress fatigue symptoms caused by underload driving conditions. Similar results were also found by Verwey and Zaidel (1999).

This notion is also supported by Atchley and Chan (2010), but they associate it with a cost: distraction. However, in contrast, Takayama and Nass (2008) suggest that interactive media can support sleepy drivers but are not necessarily harmful for non-drowsy drivers.

### 6.10 Adapt to age

There are differences in needs between young and elderly people and a starting point would be to use Blomqvist, Sirén & Davidse’s (2004) assembled design principles for the elderly. These are mainly located in the sense phase of the human information process and include: use redundant cues, such as auditory, visual and tactile feedback; increase character size; avoid glare on windscreen and displays; use auditory signals in the range of 1500–2500 Hz; design for independence of stereoscopic vision; make driver responses more self-paced; etcetera.

In addition, Ducic & Broberg (2012) suggested a system that supports the driver in being attentive to other road users at an intersection.
6.11 Avoid automation induced issues
There is limited practical knowledge about the automation issues described above in the road vehicle domain. ADI is limited to a few manufacturers that block information where there is risk for high mental workload. In automation of driving tasks, there are many examples of automation of longitudinal control, for instance ACC. The lateral support is so far limited to Lane Keeping Aid (LKA) and Lane Departure Warning (LDW) systems.

However, several ongoing research projects in the EU and elsewhere and advanced demonstrators from for instance Google indicate that a higher level of automation of driving tasks is soon at hand. Earlier research that predicted full automation on British roads by the year 2030 (Walker, Stanton and Young, 2001) seems to need an update.

Nevertheless, several principles regarding how to minimize automation induced when introducing ADI and automated vehicles has been suggested. A few of these will be presented here.

6.11.1 Adaptive automation
An alternative to static automation is adaptive automation, which represents computer assistance or task allocation between human operators and computer systems that are flexible rather than fixed (Parasuraman and Hancock, 2001). The basis in adaptive automation is the trade-off between workload and situation awareness that results as the level of automation is varied. The task manager assigns workload to either the automation or the human and it could be managed by automation, the human or the two in collaboration (Wickens and Hollands, 1999).

Evaluations of adaptive automation have focused on the performance and workload effects of either adaptive aiding of the human operator or adaptive task allocation, either from the human to the machine, or from the machine to the human. Each of these forms of adaptive automation has been shown to improve human-system performance (Parasuraman and Hancock, 2001).

It is not obvious what this means from an ADI perspective. Of course, the information can be changed manually in low workload conditions and automatically during high workload, but would the adaptive automation instead create new questions such as what to adapt, how to control and who decides (Wickens and Hollands, 1999)?

6.11.2 Hybrid displays
A solution that may reduce the negative aspects of both fully manual and fully automatic control over the information is to introduce what Hameed and Sarter (2009) call hybrid displays. The system informs the user of the planned changes and employs a management-by-exception approach (Olson & Sarter, 1998) that allows the operator to decline or modify these adaptations. For instance, if the system intends to change to
“parking” mode but the driver intends to pass by the parking space, the driver can
deny a changed mode.

This approach can be compared with a management-by-consent approach (Olson &
Sarter, 2001), where every proposed action by the system needs approval by the
driver. Management-by-exception is less demanding in terms of user-system
interaction, which may be critical in highly visual tasks such as driving. However, the
least user-system interaction would a fully automated ADI system have.

6.11.3 The team player approach
An extension or development of adaptive automation and/or the hybrid displays is the
“team player approach”. Some of the automation induced issues could be reduced or
eliminated by making the agents within the system co-operate more and better.

For instance Dekker and Woods (2002) suggest that system designers should abandon
the traditional “who does what” question of function allocation and instead make
humans and automation get along together.

Woods and Sarter (1999) claimed that the automation induced issues represent neither
“over-automation” nor “human error”. There was rather a third possibility: that they
represent a breakdown in the coordination between operators and the automation.
They argued that, instead of reducing automation or designing mainly to reduce errors,
it should be possible to tame the complexity of a system by making the automation act
like a team player.

Young, Stanton and Harris (2007) proposed that shared authority should prove to be
the most efficient approach, rather than either human or technological authority.

Klein, Woods, Bradshaw, Hoffman and Feltovich (2004) did not offer a tangible
design solution but outlined ten challenges for making automation components into
effective "team players" when they interact with people (see Paper C). In addition,
Christoffersen and Woods (2004) conclude that observability and directability are the
keys to the development of a cooperative relationship between the human and
machine agents in any joint system.

In the Team player study the greatest concern was that the nature of the different
"challenges" described by Klein, Woods, Bradshaw, Hoffman and Feltovich (2004) is
very visual in its characteristics and requires a great deal of visual interaction. Thus,
since the driving task also is very visual (Wierville, 1993), the challenges are even
greater for car system designers in automating driver tasks.

A less visually demanding approach was therefore suggested, a separate view in
which intention, skill development, limits of performance etcetera could be placed.
In this separate view, vehicle and perhaps also the infrastructure act as team players in a new team in the beginning, when they start to get to know each other. They practice and learn to know each other and then, after some time, when they have become a real team, they no longer have to show intention, express their limits of performance etcetera. The team has developed a skill that does not require reasoning or cognitive resources and works with a high level of automaticity.

This approach, which may be called “team building”, has the benefit of, after some time, becoming more “gentle” (non-intrusive) and therefore is better suited to a consumer product, such as a car, but at the same time has the same benefits as the team player approach.

However, unfortunately, before skill has developed and if the number of visible items is high, communication requires long glances. Thus, in the beginning, less should be visible and more be allowed to be visible when skill has developed. This is obviously a catch 22 syndrome.

The solution may be to show information about how automation works on different levels of abstraction. Normally the driver information only shows information on a highly abstract level, perhaps only global information that everything works fine. But there is always a possibility for the automation to zoom into a less abstract level if the system is close to the safety boundary (for instance to show that the road markings are poor) or for the driver to zoom in if he or she wants to achieve a better understanding of the complex system, like the idea behind Cognitive Work Analysis (Jenkins, Stanton, Salmon and Walker, 2008).

6.11.4 The H-metaphor

Few practical and tangible attempts to handle the potential problems that may appear in automation have been made in the road vehicle domain.

However, an example suitable for driving automation is the H-metaphor (Flemisch et al., 2003) that may serve well as an example of a team player approach. In short, the H-metaphor is a trial to establish a mental model of the automation as a horse - rider relationship to keep the driver in the control loop. The communication between the human and the horse is mainly haptic and, depending on the difficulty of the task, the rein is loose (Horse in control) or tight (Driver in control). The metaphor also includes a training phase, just like riding, which requires training.
6.11.5 Summary of how to avoid automation induced issues

Four ways to reduce automation induced errors were discussed: adaptive automation, hybrid displays, the team player approach and the H-metaphor. The team player approach was more thoroughly discussed and further developed into an approach called team building an approach that can use different level of abstraction to visualize system behaviour.

6.12 Summary of how an ADI can be carried out

ADI seems to be able to handle most of the aspects from Chapters four and five. Practical and theoretical examples have been given from both the studies included in the project and other research regarding how to design an ADI.

A zoom lens metaphor was suggested to support the driver in different contexts and levels of control, a way to illustrate uncertainty in automation to make the driver better understand system limits was presented, and several proposals for how to adapt to personality traits have been suggested.

ADI can also support different levels of skills. For instance, by using historical data well-known areas may be treated differently from novel ones and a well-known system may look different from an unknown one.

ADI may also have the possibility to support age and gender in different ways. Age may for instance affect the appearance of and information presented in intersections.

Drivers’ differences in response to mental demand can be supported with an ADI. Too high a mental workload can be reduced and too low can initiate functionality such as moving information in time or adding a pre-load task. One example was to increase demand in low density traffic. It would also be possible to reduce possible mismatches between real world complexity and a driver’s invested effort by information.

ADI can support sleepiness by identification of sleepiness, give motivation to take actions and provide means to avoid sleepiness.

Finally, to avoid automation induced issues, a team building approach was suggested.
7 Summary of studies (appended papers)
This chapter is a short summary of the studies carried out in the project. For a more complete introduction, method descriptions, results and conclusions, see the particular paper.

7.1 The Work Domain Analysis study (Paper A)

Introduction
The aim of this study was to identify ways to support problem solving and decision making in a driving information context and to study gaps, overlaps and strong and weak relations between the driver information functions and the purpose of the functions.

Method
Work Domain Analysis (WDA) (Vicente, 1999) was used to decompose the purpose of the driver information down to the component level. WDA is the first step of five in Cognitive Work Analysis (CWA). CWA belongs to the category of Ecological Interface Design, which aims to aid the design of human centred interfaces and systems that support problem solving and decision making in complex sociotechnical systems. Naikar et al. (2005) provide several steps to create the boundaries for the CWA. These steps have been used and are described briefly below.

The method is mainly based on the work of experts. Researchers from Luleå University of Technology and Volvo Cars engineers were therefore involved in the project. Researchers from Brunel University, UK, provided experience from other WDAs.

Result
The "functional purposes" were decomposed into "abstract functions", e.g. support choice of transportation, reduce energy exposure, improve friction, and maintain lateral and longitudinal distance. Further decomposition down to the "physical form" showed several weak and some unexpected relations between the purpose and the system. For instance, one conclusion was that the relation between speedometer and safety was weak. The weak relations and the gaps then served as input for design implications, not only functions placed in the vehicle. Implications suggested were, for instance: provide the driver with data about what is going on ahead without entering a destination (feed forward), support congestion avoidance, provide a driving coach to improve green driving, indicate the greenest route in a navigation system, feedback on fuel efficiency and green driving performance and the perhaps controversial suggestion to compare different ways of transportation from a cost perspective.
**Conclusion**

WDA was a very useful framework for investigating functional content in relation to its purpose. Filling the gap between the physical function and functional purpose clarifies why or why not a function is used.

It was concluded that planning could be improved in comparison with today's systems by e.g. Internet services and pre- and post-trip information. New features in the navigation system, such as route optimization based on safety or carbon footprint, could improve both safety and environmental friendliness. Feedback or Edutainment (Education by Entertainment) could also serve as a way to improve safety and green driving. Another more general conclusion is that the decomposition also showed the importance for a designer to ask the question “why?” when designing a product.

**7.2 The Context study (Paper B)**

**Introduction**

This study deals with a first step towards the context adaptive functionality of ADI. Driving a car is a complex task for which the driver needs appropriate information to fulfil his or her goals. New technologies enable control adaptive to driver state, task, personality etc. and to the context. The aim of this study was therefore to investigate what information people perceive that they need and want from the car in different contexts and to what extent there is consensus about the function.

**Method**

The study was a combination of a context walkthrough interview and a rating of functions. The purpose of the interview was to try to make the participants think beyond today's design and avoid bias of current functions of cars and to gather data that give an understanding of how people think in different contexts.

The numerical data (Rating) in this study were used to analyse the functions’ levels of importance and level of consensus among car drivers.

Thirty-three Swedish private car drivers participated, 14 men and 19 women with an average age of 42 years.

The contexts and functions were chosen by five Safety and Human Machine Interaction (HMI) experts at Volvo Car Corporation and the Luleå University of Technology. The experts were later also used when developing the Context Function Matrix (CFM), heavily inspired by the “Context Activity Template” by Naikar et al. (2005). CFM is a matrix with the contexts in the columns and functions in the rows.
**Results**

The results show that people need and want different types of information in different contexts. It was furthermore indicated that there is sometimes a difference in drivers’ opinions about what should be presented by the car and that there is varying consensus over different functions in different contexts. The rating result was illustrated by an easily perceived Context Function Matrix.

**Conclusions**

The interviews, function grading and open end answers in the study gave an indication that drivers have different perceived needs and desires in different driving contexts. A function that is very important in one context can be of little or use in another context.

The ratings’ average value gave a hint about what functions are needed or wanted, and the standard deviation indicated the extent to which there is consensus about each function.

A Context Function Matrix was created to illustrate the information needed in different contexts in a simple way for designers. The CFM can be utilized in the design of new context ADI interfaces.

### 7.3 The Team player study (Paper C)

**Introduction**

Automation can cause “human factor” problems. One approach is to make automation become a team player. A team player agrees on a common ground, shows intention, shows reasoning and expresses its limits of performance and so on. This approach was applied to ADI in the present study.

**Method**

Ten experts in different automated in-vehicle systems at Volvo Cars took part in the study. In advance of the interview, the experts were sent an e-mail with a common driving scenario as a starting point for the interview. The experts were also provided a list of potential problems regarding automating information flow. The problems described were over-trust, under-trust, skill degeneration and workload when automation fails. Interviews with the experts were conducted according to the Delphi procedure to avoid bias from other participants. The starting point was that the agents in automation should act as team players. After the interviews, a workshop was held to summarize and discuss the findings.

**Results**

The study resulted in the definition of a "team player", where it was stated that a "team player is someone who achieves an improved result by working together rather than individually and has a holistic view". Furthermore, answers and practical
examples were given of how the system agents can share common goals, show intentions, be future oriented, show reasoning, explain reasoning, share representation of the problem state etc.

The greatest challenges for the team player approach in a vehicle were:

- To keep communication on the correct level
- To match the mental models of the drivers
- To create robust solutions acceptable and enjoyed by most
- To understand drivers’ intention

**Conclusions**

The experts found the team play approach both challenging and interesting. However, they also found difficulty in combining the increased visual workload required to be a “team player” with car driving, which is already visually, manually and cognitively challenging. The experts believed that the approach described by the researchers rather described agents before they had become team players than when they were team players. What is needed is “team building”; the solution suggested is a compromise and can be described as a separate view showing intention, reasoning, limits of performance, negotiations etc. and is the most suitable solution.

7.4 The **Personality study (Paper D)**

**Introduction**

The focus on the road user and possible ways to improve safety have led researchers to identify groups of road users that are supposed to be "accident prone".

Personality trait can be defined as habitual patterns of behaviour, thought and emotion (Kassin, 2003), and some personality traits are well known to be accident prone. One personality trait that predicts accident involvement is sensation seeking. If we know that a road user is a sensation seeker, it may be possible to adapt the way the warning or information message is transferred to the driver (Palmgreen et al., 1991).

This study investigates if, by means of driving characteristics such as lane keeping performance, speed choice, distance keeping performance or brake behaviour, together with information about gender and age, it is possible to identify and thereafter design and adapt driver information to the personality trait “sensation seeker”.

**Methods**

The material for the study was collected in the European Large-Scale Field Operational Tests on In-Vehicle Systems (euroFOT). Data from 55 women and 81 men with an average age of 46.7 years (SD=9.0) were included in the study.
Background data such as information on demographics and data from attitudes and sensation seeking surveys were collected. Driving characteristics data such as lane keeping performance, speed choice, distance keeping performance and brake behaviour were recorded among the same persons.

The sensation seeking score was first correlated with different driving characteristics variables. A multiple regression analysis was then made.

**Results**

Several significant correlations were found between the sensation seeking score and driving characteristics. The highest correlation for men was found in: number of lane departure warnings, Number of Driver MONitoring (DIMON) warnings and minimum distance to the preceding vehicle. For women, the correlations for speed and Mean of Time Head Way with sensation seeking score were strongest; for the whole population, age, minimum distance to the preceding vehicle and the mean value of the distance to the preceding vehicle gave the strongest correlations.

Six significant models using driving parameters were created by combining gender (male, female and all) with age (included or not included). The $R^2$ adjusted ranged from .132 to .272, which means that the variance at maximum can explain the variance by up to 27.2 percent.

**Conclusions**

Several parameters significantly correlated with the SS score and it seems possible to some degree to predict the level of sensation seeking. System designers may now have small opportunity to adapt their system to a driver’s personality. The effect of the model is not very strong, and more research is needed to tune it. One possible way to proceed is to find other parameters that were not available in the current study and that indicate sensation seeking. These may be, for instance, belt usage, speed in relation to legal speed, high volume of the stereo and glance behaviour.

Other traits may be considered for adaptable driver information, for instance to avoid problems with trust and acceptance of new technology.

A supportive rather than a prohibiting approach was recommended, such as tailor safety campaigns, adapting driving training, stronger messages with a component of surprise for sensation seekers, replacing risky behaviour with non-risky behaviour but still with an equally stimulating task, avoiding monotonous driving journeys for high sensation seekers, designing to increase trust and acceptance for drivers with *internal LoC* and better calibrating trust for *externals*. 
7.5 The *Drowsiness* study (Paper E)

*Introduction*

Up to 30% of accidents are caused by drivers that have fallen asleep. Researchers believe that the only way to avoid falling asleep is to stop and take a short nap. However, recent research shows that cognitive interactive games can also be helpful. This paper deals with the discrepancy between what researchers believe is helpful and what drivers really do when they become drowsy.

*Method*

A small pilot study was performed to obtain as many action options as possible to choose from to avoid sleepiness. Fourteen different activities to countermeasure sleepiness were identified. An Internet survey was created. The survey contained background questions and the opportunity to choose one or several of the 14 actions that they use when they felt tired. They were then asked if their activity worked, how often they used the activity, on which road type they most easily became tired, the length of time after which they started to become tired and at which time they got tired. The 77 participants were recruited from different social media, such as Facebook.

*Results*

The most common answers to the question “What do you do when you drive and start to feel tired?” was: change seating position, pull over and get some fresh air, increase the fan and reduce temperature and play loud music. Only 3 percent of the participants pulled over to sleep.

The participants believed that their method worked fairly well, and the most common frequency of use was “a few times a year” and “a few times every month”. They became most tired on motorways, after three to four hours of driving and in the evening, afternoon and night.

*Conclusions*

The conclusion is that there is a large discrepancy between what researchers believe is helpful and what drivers really do when they become drowsy.

Activities that have a cognitive character are not very common despite the fact that recent research shows that this may reduce drowsiness. However, verbal activities seem to be used more often and can be categorized as a cognitive task.
The following possible countermeasures were suggested:

- Automatic seat adjustment/movement. The seat starts, on request, to move slowly after some hours.
- Reduce temperature and increase fan automatically when there are indications of poor alertness.
- The car suggests a coffee break.
- Singing seems to be fairly efficient according to the experts and is used in 6 percent of the answers. Can a Karaoke activity without the text row be efficient?
- If games are correctly designed so that they do not distract, they may be helpful to reduce accident caused by sleepiness.

7.6 The Mismatch study (Paper F)

Introduction
Drivers most often adapt their behaviour to drive safely and, when a stressor appears, such as an increased risk in a traffic scenario or when drivers select to engage in other tasks than the driving task, they take different actions to compensate for the changed demand. One way to compensate is to mobilize effort. The effort mechanism is active in the case of attention demanding information processing, or in the case that the operator’s state differs too much from the required state (is outside the comfort zone).

To be able to understand why they sometimes do not adapt their behaviour, this paper was meant to contribute to a first step towards a model to interpret driver behaviour.

The purpose of this paper was to define mismatch scenarios that could occur while driving and to arrange these scenarios in a framework that emphasized driver behaviour.

Method
A literature study and a workshop with experts were performed to gather information to the framework, which was supposed to interpret driving situations that contain combinations of driving related and non-driving related tasks. The suggested framework was based on previous research on workload and divided into three constructs that may be aligned or separated:

1. Real world complexity (RC) describes the combined complexity of a single and/or multiple tasks that a driver engages in during driving in a specific situation.
2. Subjective complexity (SC) describes the perceived complexity or the expectancy towards a specific situation. The subjective level can differ depending on personality, self-confidence etc.
3. Invested effort (IE) describes the amount of effort that a driver chooses to invest in relation to the perceived complexity in a specific situation.

Moreover, it was defined that, if one or more constructs failed to match with any other level in the framework, a mismatch had occurred. After defining the terms framework and the mismatch, they were discussed in a one-day workshop with six human factors professionals. The literature study and the workshop results were summarized in a report, which was the basis for this paper.

**Results**

Based on the definition above, 13 mismatch scenarios were identified. One scenario represents normal driving while 12 scenarios were mismatch scenarios that indicate increased probability of risky driving behaviour and/or worse User Experience (UX).

- In five of the scenarios, the subjective complexity was higher than the real world complexity (SC>RC). These mismatch scenarios indicate increased risk or worse UX.
- In four of the scenarios, the invested effort was higher than needed according to the real world complexity (IE>RC). These mismatch scenarios indicate increased risk of fatigue.
- In five of the scenarios, the real world complexity was higher than the subjective complexity (RC>SC). These types of mismatch scenarios indicate increased probability of risky driving behaviour.
- In five of the scenarios, the invested effort was higher than the subjective complexity (IE>SC). These types of mismatch scenarios indicate an increased probability of better driving behaviour and better UX.
- In four of the scenarios, the subjective complexity was higher than the invested effort (SC>IE). These types of mismatch scenarios indicate increased probability of risky driving behaviour and worse UX.

**Conclusion and Discussion**

The framework developed describes mismatch scenarios that affect driving safety and UX. The framework is based on the assumption that drivers adapt their behaviour and drive safely in a majority of all driving situations, and that they indeed have available resources to solve the majority of all driving situations. However, when drivers for different reasons misinterpret the actual situation, the framework suggests that there is a mismatch between one or two constructs.

The mismatches may however be minimized by driving information or design of the environment. This information may include designing the road environment and in-vehicle systems to be perceived as easy as to use, feed forward information or education, coaching or social media.
In conclusion, the results reported here offer an opportunity to develop a safety and user experience model with descriptions and implications for interaction design. The framework can also be further expanded to be design guidelines for in-vehicle systems.

7.7 The Task pre-load study (Paper G)

Introduction
It has long been accepted in ergonomics research on mental workload that overload and underload are equally detrimental to performance. In Malleable Attentional Resources Theory, underload is explained by a shrinkage of attentional capacity in conditions of excessively low mental workload.

One practical implication of MART as an explanation for underload is that attentional capacity may be optimized if the operator engages in some additional task activity. Thus, where mental workload is otherwise low, the operator undertaking an additional task could artificially stimulate his or her attentional resources, avoid underload and improve performance.

In the current paper, we propose and evaluate a conceptual adaptive system that takes the two approaches described above in combination. That is, it provides the driver with additional, task-related activity during periods of low workload, which is specifically designed as preparatory activity for a later, anticipated peak in demand.

Method
A 2x2 mixed design was used for the study. The two independent variables were low or normal task workload. The second independent variable, a within-subjects factor, was presence or absence of the pre-loading task, a series of hazard perception questions. In addition, at the mid-point of the run, a critical event occurred which required drivers to react to an overtaking car pulling into the subject vehicle’s lane ahead, and then braking harshly to a standstill. Finally, a peripheral detection task (PDT) was embedded into the scenario for an objective measure of attentional capacity.

Dependent variables included primary task measures of driving performance (whether or not they crashed in response to the critical event), number of missed responses and reaction time to the PDT, and subjective mental workload using the NASA Task Load Index.

In total, 27 participants recruited from the Brunel University driver participant pool took part in the study, 14 of whom were male. The average age of the sample was 36.0
years. Fourteen participants were randomly allocated to the low workload condition and 13 to the high.

The Brunel University fixed-base driving Simulator (BUDS) was used for the study. After a five-minute test drive, instructions were given for the main experimental trials, including the directive to drive at a constant 60mph, as well as information on the pre-loading task where relevant.

At the end of each trial, two sets of NASA-TLX scales were given, one for the first half of the scenario (up to and including the first brake event) and one for the second half of the scenario.

**Results**

A 2x2x2 ANOVA, comparing the within-subjects factors of pre-loading task and pre- or post-critical event, against the between-subjects factor of workload condition, did not reveal any significant main effects or interactions.

A chi-square test did not reveal a significant result the total frequency of missed responses to the PDT.

A 2x2x2 ANOVA (as per the PDT reaction times) revealed a significant main effect for the pre-loading task, and a significant interaction between the pre-loading task and the phase of the trial (pre- or post-critical event). Furthermore, results approaching significance were returned for the pre- vs. post-critical event phase of the trial and the interaction between phase and workload condition.

The presence of the pre-loading task resulted in increased scores on the TLX. The source of the interaction between pre-loading and phase of drive was a significant decrease in overall workload between pre- and post-critical events only in the conditions with the pre-loading task ($t(26) = 2.66, p < 0.05$); in contrast, this difference was non-significant for conditions without the pre-loading task.

Data show a marginal drop in overall workload across all conditions between the pre- and post-critical event phases of the drive. Again, the trend towards an interaction was due to a significant reduction from pre- to post-critical event only in the normal workload condition; this difference was non-significant in the low workload condition.

**Discussion**

The pre-loading task had no effects on any of the objective performance measures, even though it did have an impact on subjective mental workload. There are several possible explanations for these results.
• It is an accepted limitation of such methods that retrospective rating of a task is prone to inaccuracy.
• The pre-loading task does not have the anticipated effects in terms of compensating for underload or that theories of underload are in fact automation-specific.
• The low workload condition in the present experiment was not low enough to induce underload – despite the fact that we had pared the driving task back to a minimal amount.
• The pre-loading task was not a sufficient load.

Although the results did not prove the hypothesis, the pre-loading task was clearly noticeable to participants and it may have an effect. More work needs to be done on making the experimental task more distinct before concluding that a pre-loading task is ineffective.

7.8 The Uncertainty study (Paper H)

Introduction
A simulator study was conducted to investigate the impact of visualizing car uncertainty on drivers’ trust during an automated driving scenario.

Method
A between-group design experiment with 61 Swedish drivers (31 male, 30 female employed by Volvo) between 27 and 58 years old was carried out. The study took place in Volvo Cars’ simulator, where a continuous representation of the certainty of the car’s ability to autonomously drive was displayed to one of the groups and was absent for the control group.

The participants drove the car simulator for approximately nine minutes through a snowy and foggy two lane country side road. Visibility due to weather varied from 0% to 100%. When the visibility was worst, the car certainty representation showed the lowest level and the automation stopped working, resulting in the driver having to retain control of the car.

After the test session, the participants were asked to complete a questionnaire about their trust in the system.

Results
The results show that, on average, the group of drivers who were provided with the uncertainty representation took control of the car faster when needed, while they were, at the same time, the ones who spend more time looking at other things than on the road ahead.
Discussion
Drivers provided with the uncertainty information could, to a higher degree, perform tasks other than driving without compromising driving safety. The analysis of trust shows that the participants who were provided with the uncertainty information trusted the automated system less than those who did not receive such information, which indicates a more proper trust calibration than in the control group.
8 Methodological considerations

The methods presented in Chapter 2 are numerous, which can apparently be both negative and positive. The positive is that many new ways of investigating a research question have been learned; on the negative side is that it is very time consuming to learn and understand all the necessary concerns of a new method.

This section covers reliability considerations for each of the areas of test samples, data acquisition and data analysis, which were earlier described in Chapter 2. Validity is discussed from a more general perspective.

8.1 Reliability

Reliability is the degree to which an assessment tool produces stable and consistent results. Reliability was tested as much as practically possible when new methods were developed.

8.1.1 Test samples

The number of participants in the studies seems to be fairly appropriate. However, the large variation in the performance and workload ratings among the participants and the fact that there are interesting tendencies in the Task pre-load study may require a new study with a larger number of participants.

In the Context study, contexts were decided by Human Machine Interaction (HMI) and safety experts, and the contexts are thus possibly more important from a safety perspective since the focus in these disciplines is often safety. It is not confirmed whether this reflects the drivers’ perspective of the contexts in which they find support needed or wanted. Perhaps other areas are equally important for the common drivers. However, since the method used was mainly a between-subjects study, it would be possible to add contexts afterwards where other properties are more important.

When using experts, it is necessary to consider bias between participants. The risk is that participants can have a considerable influence each other in a group. The Delphi procedure (Kirwan and Ainsworth, 1992) used in the Team player study first gathers judgments from experts individually; the expert then got the judgment from the previous experts and could re-evaluate his/her own judgment. The bias from other members was obviously reduced, and it was possible to quantify the participants’ response before they learned about the other group members’ opinion.

Recruitment through social media is convenient, and it is easy to recruit a high number of participants quickly. However, control over the respondents answering for instance a questionnaire such as in the Drowsiness study is of course limited. The main idea was to identify different activities and give an estimate of what drivers do when they get tired and to what extent they use that behavior. Many participants were
needed for this. However, an effect of the poor control of the participants was that the average age was higher than expected. This may have a large impact on the results, since younger drivers are over-represented in the drowsiness crash statistics (Åkerstedt and Kecklund, 2001).

It is a fact that driving behavior and the need and attitudes regarding support are different in different countries or cultures (see for instance Lindgren, 2009). In the current thesis, drivers from Sweden and the UK took part. It may therefore be discussed whether the studies should be repeated in other countries.

8.1.2 Data acquisition

Data acquisition is a vital area to reflect upon. For instance, Henry Ford said “If I had asked people what they wanted, they would have said faster horses”. This saying is probably only an anecdote but it describes one of the challenges in this thesis.

It is difficult to ask people whether they want something, such as an ADI system, that does not exist. The solution in the Context study was to make the functions more abstract, which made the participants think an extra time and not fall into the “what I have today” trap. One indicator that showed that this actually worked was that, instead of just grading the function without much thought, the participants gave the impression of thinking twice before giving their grade, and they moved sometimes up and sometimes down one level of abstraction, just as intended.

A second indicator was that very common functions such as “show speed” showed great differences in how they were graded in the different contexts. This way of thinking may also be applicable in other situations where it is necessary that people judge information as needed or wanted.

In the Context study, the rating question “show average speed” was purposely repeated to judge whether the participants were able to give a similar grade of the function twice. The difference between the mean values was small with one exception, which indicates that the participants were able to repeat their response.

The material from the euroFOT was originally not collected for the purpose of finding correlations or creating regression analysis from sensation seekers and car data. Some data were therefore not available. The reliability in the Personality study may be increased and the models strengthened by knowledge about, for instance, belt usage, entertainment volume and glance duration.

Some questionnaires had been used by others before. For instance, the NASA-tlx questions used in the Task pre-load study are well established in mental workload research. In the Uncertainty study, a modified version of the trust in automation scale was used and, in the Personality study, the Sensation Seeking Scale was modified. The
changes were minor, and it is not expected that these affected reliability. When
questions were designed specifically for this thesis, general guidelines for
questionnaires were used (Andersson, 2001).

8.1.3 Data analysis
Data analysis took place in the Task pre-load, Uncertainty, Personality and Context
studies, the first two to investigate whether the hypothesis could be falsified, the third
to see whether there was a correlation between and possibility to predict personality
from driving data and the fourth to see how high people rated a function and their
level of consensus. The statistical analysis made in the four studies was fairly straight
forward and was a very useful tool in the research.

It can always be discussed whether the correct methods were used and whether these
were carried out in a correct manner, especially since they were often used for the first
time for the author. To reduce the risk for large methodological errors, early
collaborations with more experienced researchers were established, such as with the
Brunel University in UK.

8.2 Validity
Validity refers to how well a test measures what it is meant to measure.

One great methodological challenge, even perhaps too great, was to measure the
performance effects of adding a pre-load task in low mental workload conditions. The
simulator tests in the Task pre-load study failed to create a mental workload level that
corresponds to “exceptionally low” (Young & Stanton, 2002), even in a driving task
that was extremely simplified such as in the scenario without the task. The explanation
may be found in the characteristics of the simulator (no moving base etc.) or that the
simulator situation in itself by its news value for the participant increases mental
effort. For most people, it is probably much more exciting to drive in a simulator than
in an ordinary car, and the ecological validity, especially in the low mental demand
region, may therefore be questioned.

The data from the euroFOT project used in the Personality study on the other hand
have high ecological validity since they are collected from ordinary people on real
roads. The downside of FOT is that it requires a huge organization; thus, if a change is
requested, it is probably difficult to achieve.

One of the challenges in the Context study was to make people think of: first, a
generic context rather than one particular context; second, avoiding serial position
effects (e.g. Wickens, 1992) that may occur if the contexts are presented in sequence,
such as in a movie; and third, that the pace at which a driving task is performed may
be important. If the participant is presented a movie in which someone else is driving.
the pace could be different from the participant’s own, and this may well have an effect on the result.

The solution was a paperboard with nine different but similar photos that created a context (for instance an intersection). There are indications that this worked as intended. The participants browsed the board and did not seem to favour any of the pictures. They discussed the whole sequence of the context, they mentioned events in their own experience that could be applied to the pictures and they discussed their own pace in similar situations.

Another interesting challenge in the Context study was that a function could also be not applicable, inappropriate or even dangerous in a specific context. For instance, “show speed” may be considered not to be applicable before driving and after driving and “ability to surf on the Internet” may be inappropriate and dangerous while driving in an intersection. A simple grading scale from for instance 1 to 5 would not have been appropriate. A waste bin was for this reason added to the scale.

In the studies both involving non-professional and/or expert participants, a great deal of effort was invested in making them think beyond current knowledge, avoiding the influence of others and being as ecologically valid as possible. This resulted in a few new methods that must be further validated in future work.
9 Conclusion

The aim of this thesis was to obtain an improved understanding of ADI, to bring further what we currently know and strengthen knowledge of the adaptive control of driver information, and to give some possible directions and thereby make possible new means to support drivers.

This was done by identifying the purpose of driver information, areas to adapt (input factors) and possible ways to adapt. During the work, it was also strongly indicated that one of the potentially largest contributor to the failure of an ADI was automation induced issues. Figure 17 summarizes the different options and challenges and some interrelations between the options when designing an ADI system such as has been described in this thesis.

**Figure 17.** Summary of the project. The letters in superscript (A-H) are the papers written.

9.1 Summary of research questions

Below follows a brief summary of the main conclusions regarding the research questions.
**RQ1. What are the purposes of future driver information?**

It is suggested in this thesis that the main purpose of driving information is to support the driver in achieving goals such as a safer, more environmentally friendly, more efficient, legal and enjoyable transportation. The adaptive system can support these goals by providing correct information and feedback.

**RQ2. What can adaptable driver information support?**

ADI can support the driver at all levels of control, operational, tactical and strategic, and even further in how to set goals for the driving task and encourage good driving behaviour.

ADI can support the driver at the different levels of control from trying to affect the driver’s goals in driving and support drivers’ goals in more operational tasks such as parking. ADI may also help drivers to stay within their comfort zone by visualizing risk or certainty.

It seems possible and beneficial by means of driving data to identify and thereafter adapt how a message is communicated to different personalities. Sensation seekers need strong and surprising messages, extroverts and people susceptible to boredom get tired faster and need stimulation while introverts need less. External LoC rely less on technology and internal LoC more.

Skill and strong schemata (either correct or wrong) will be developed over time. The driving skill affects the mental effort. Well learned behaviour (skill based) is highly automated and requires less effort while novel situations (knowledge based behaviour) require more. Too many modes may reduce the development of skill; on the other hand, manual instead of automatic change between the different modes may cause distraction.

ADI can support the driver in maintaining his or her mental workload within the safe task load area by blocking of information, shifting information in time or changing modality when the demand is too high, such as in dense traffic or a complex context, and increase mental workload by triggering or suggesting an extra stimulating task during too low a mental demand, such as while driving on a monotonous road with low traffic density.

Sleepiness may be counteracted by increased mental demand. Similar to when the demand is low, an interactive cognitive task can be triggered if it is indicated that the driver is sleepy.

**RQ3. What are the negative effects of adaptive driver information?**

ADI changes automatically and there may be so called automation induced issues that make the purpose of driver information vanish. These include: mode confusion,
function allocation, over and under trust, locus of control, skill degeneration and too low/high a mental workload. Research has shown that the most efficient way to reduce these issues is to make the driver and the automation (the agents) get along together and become team players. The team players should share goals, show intention, and show limits of performance and state. However, for cars, a consumer product, in which visual demand is high, an approach can be where information vanishes when agents have become a “team”. A team does not show, it knows. This approach may be called “team building”.

**RQ4. How can adaption be carried out?**

Several examples of how ADI can be carried out have been suggested and some even illustrated, for instance the zoom metaphor that has partly been industrialized in Volvo Cars, the visualization of certainty of agents in automation and the app that intends to be triggered if the mental demands are too low or if the driver gets tired.

Theoretical suggestions have been developed regarding how to design for different personality traits, how to move information to periods of lower demand in order to maintain performance and a mismatch framework.

At first glance, there are perhaps a few controversial suggestions in this thesis. For instance, a game is recommended during boredom or low mental demand. There is a strong notion in this thesis that it is possible to think beyond banning and blocking and instead try to understand behaviour and then give support. This approach would also support the functional purpose of driver information called “enjoyable”.

### 9.2 Contributions

The research and industrial contributions are described below.

The largest research contribution of this project is probably that it has extended ADI to also include other areas than have been included in previous research. For instance, it would also be possible to adapt to the low mental workload area and personality trait. The project focused on low mental workload and came up with several possible solutions to avoid the negative effects of these situations.

A step was taken towards a methodology that investigates functions in different contexts. The thoughts regarding abstraction of functions may be used elsewhere.

A new framework developed suggested the possibility that a mismatch between real world demand and effort invested may be an equally large problem as mental underload or overload.
The team player approach was adapted to cars, which resulted in a new approach that may be called team building. These approaches were further studied and highlighted the importance of uncertainty in the information in automated systems.

The main *industrial contributions* are summarized in the following:

The Work Domain Analysis resulted in new features and new services being further investigated. Work is progressing.

Several design suggestions have been given in the project. The zoom lens metaphor has already resulted in partly implemented solutions (see figure 11).

A stimulating and attention enhancing system during low workload, currently called ATTAPP (ATTention APPlication), has been developed and will soon undergo large scale testing (see figure 14).

The interaction between the human agent and automation has been highlighted, and several concrete design solutions have been suggested to minimize automation induced issues.
10 Further research

During the work with this thesis and the papers appended, many new and interesting questions have arisen that have not been possible to investigate in the scope of this project.

In the Personality study, only one personality trait was correlated with driving data. It would be beneficial to investigate many more types of personalities that are accident prone or affect how driver information should be carried out. For instance, how can trust and acceptance be better calibrated for different extremes of LoC (LoC seems particularly interesting when cars can now drive autonomously)? Furthermore, can an interesting and challenging quiz substitute more hazardous behaviour such as speeding among some personality traits with a normally low cortical arousal level?

A related question is of course whether drivers accept that the car senses behaviour and develops and keeps a user model of the personality trait in the car or in the cloud. Such information may be abused and raises questions about personal integrity.

It was indicated in the Context study that there is a large discrepancy between drivers concerning what the car should do and what the driver should do. This puts a greater focus on more research regarding function allocation and the concept of LoC.

The Uncertainty study compared a concept showing car certainty with a concept showing no certainty information. Two options are still to be investigated: show information about how certain the driver is only and show information about how certain both the driver and the vehicle are (illustrated in figure 12). The first actually exists in a way; several car manufacturers have introduced driver alert systems that warn drivers if they seem not to be alert. However, alertness is not described in terms of uncertainty, they do not yet take any further actions and they have not been utilized in automation.

Instead, the automated agent would be able to use this driver uncertainty information to maintain the total systems certainty (see figure 18). For instance, the automated system can increase headway or warn earlier if the driver is less attentive (certainty missing) and, in contrast, be able to drive with less “automation certainty” if the driver is attentive and prepared to intervene if necessary (certainty overlap); the level of authority between the agent then changes dynamically, such as in the team player approach.
However, research is needed as to how the human agent will respond when the car tells him or her that he or she is uncertain and that this means that the total system is too uncertain to drive. Furthermore, will they understand that they can be “rewarded” with higher automation availability if they are more attentive.

Further research on how to express certainty or uncertainty is also needed. For instance, can a car express uncertainty in a non-visual way?

The mismatch framework is still in its cradle and needs to be further explored to be useful. Questions that need more work may be:

- Which mismatch scenarios are relevant for safety and user experience?
- Are there differences between single and double mismatch scenarios in terms of safety?
- Do skill and motivation affect mismatch?
- How do the different factors that influence driving behaviour relate to each other?
- How can the defined mismatch scenarios be confirmed and measured, during driving, during tests in simulators and by subjective methods?
- Will this framework be easier to use for designers of in-vehicle systems compared to previous workload models?

This thesis has delivered several but only fragmented suggestions regarding what an ADI can look like. One of the main tasks in future research on ADI must therefore be to design and assemble a complete ADI in practice.

Figure 18. Principle for total system uncertainty
This project did not evaluate adaptive control in itself. To evaluate an ADI, several new criteria may be compared to common driver information such as how well a goal is supported, how well automation induced issues are dealt with etcetera. Methods for how to evaluate ADIs are needed.

Finally, the findings in the current thesis and several papers already mentioned (Gershona, et al. 2009; Verwey and Zaidel, 1999; Atchley and Chan, 2010; Olson et al., 2010; Victor, et al. 2014) present a nuanced view of interactive media in cars. Interactive media can reduce driving performance by distraction but may also have a preventative effect. More research is needed to understand how this obviously positive effect can be exploited.
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Work Domain Analysis of Driving Information

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ABSTRACT

In order to drive in a safe and environmentally friendly manner a driver needs support on the skill based, rule based and knowledge based level (Rasmussen, 1986). It can be argued that today's driver information mainly supports skill and rule based levels while the complex task of driving also needs support on the knowledge based level, e.g. problem solving. The aim of this study was to identify ways to support problem solving and decision making in a driving information context and to study gaps, overlaps, strong and weak relations between the driver information functions and the purpose of the functions.

Work Domain Analysis (WDA) (Vicente, 1999) was used to decompose the purpose of the driver information down to the component level. WDA is the first step of five in Cognitive Work Analysis (CWA). CWA belongs to the category of Ecological Interface Design that aims to aid the design of human centred interfaces and systems that support problem solving and decision making in complex socio-technical systems.

The study was performed by researchers from Luleå University of Technology and Volvo Cars as well as members of a Driving information project. The study was limited to driver information systems in private cars which means that the main purpose of the systems was to support drivers' goals e.g. navigate or maintain speed but also being environment friendly, etc. It should also be mentioned that driver information not only was limited to information within the car. Before and after driving was also included. The WDA identified five functional purposes of driving information: To support safe, efficient, environment friendly, legal and enjoyable transportation.

The "Functional purpose" was decomposed into “abstract functions” e.g. support choice of transportation, reduce energy exposure, improve friction, and maintain lateral and longitudinal distance. Further decomposition down to "physical form" showed several weak and some unexpected relations between the purpose and the system. For instance, one conclusion was that the relation between speedometer and safety was weak. The weak relations and the gaps then served as input for design implications.

In the design implications part it was concluded that planning could be improved in comparison with today's systems by e.g. internet services and pre- and post-trip information. New features in the navigation system, such as route optimization based on safety or carbon footprint, could improve both safety and environmental friendliness. Feedback or Edutainment (Education by Entertainment) could also serve as a way to improve safety and green driving. A rather controversial and perhaps unrealistic suggestion is that a private car could provide statistics or data about safety, environmental friendliness or efficiency (Cost) for different types of transportation in order to make the choice of transportation optimized.

Another, more general conclusion is that the decomposition also showed the importance for a designer to ask the question "why?" when designing a product.
INTRODUCTION

Car driving is a complex task and can be described in many different ways. Rumar (1986) decomposed car driving into the following categories: To plan the trip, to navigate, to follow the road, to interact with other road users, to interact with the car and to interact with different in-car devices. These different subtasks of driving can be classified into the framework developed by Rasmussen (1986), that is, skill based, rule based and knowledge based behaviour. Well practiced tasks, like steering in order to follow the road, may be regarded as skill based processes. Other tasks, like overtaking other vehicles, may be regarded as rule based processes. Relatively few functions in the car of today provide support for the knowledge based processes of car driving, such as trip planning and strategies to meet unexpected events or problems during a trip. An exception might be the navigation system that both could act as a tool to support navigation and support re-route if the road is blocked ahead.

In order to drive safely a driver needs support on the skill based, rule based and knowledge based level. It can be argued that today’s cars mainly provide support for skill based and rule based processes of car driving. The speedometer could be used to compare the present speed with the legal speed limits and the fuel gauge could be used to judge how much there is left in the tank. These two functions could be considered to support rule based behaviour. In order to support knowledge based behaviour some cars are equipped with trip computers that can calculate how far you can drive until the fuel tank is finished. The introduction of Advanced Driver Assistance Systems (ADAS) has offered the driver warnings or mitigation if the well practiced tasks, as described above, fails. These systems can be described as supporting skill based or more or less automated behaviour.

The transportation system can be regarded as a complex socio-technical system, containing many different and interacting sub-systems. A characteristic property of a complex system is that it is not possible to predict everything that might happen in the system. Accidents on the road, problems associated with the infrastructure, and other unexpected events may be some examples of events that are vary hard to predict.

Consequently it seems important to provide car drivers with some support to meet events that involve problem solving or knowledge based behaviour.

Ecological Interface Design (EID) is used to aid the design of human centred interfaces and systems that support problem solving and decision making in complex socio-technical systems. An ecologically designed interface is one that has been designed to reflect the constraints of the system in a way that is perceptually available to the people performing activity within it, and one that supports users in taking effective action and understanding how these actions will move them towards the achievement of their goals (Burns and Hajdukiewicz, 2004).

Cognitive Work Analysis (CWA) (Vicente, 1999) provides a useful framework for the analysis of the various constraints that are imposed on activities within a particular system.

CWA is divided into five phases. First: Work domain, represents the system being controlled. Second: Control tasks, are the goals that need to be achieved. Third: Strategies that are the generative mechanisms by which control tasks can be achieved. Fourth: Social organization and cooperation, deals with the relationships between actors and finally the fifth: Worker competencies, represents the set of constraints associated with the workers themselves. It might feel peculiar in this context to call drivers “Workers”. However, the meaning is that something is produced; in this case it is transportation.

Probably the most commonly used phase is the first, Work Domain Analysis, which also was used in the present study.

Related research

Several studies that have used CWA to study vehicle design implications have been made. Salmon (2007) uses the first step, Work Domain Analysis, in CWA to study Intelligent Transport Systems (ITS). A study by Birell (2008) used CWA to develop a technological device which will encourage drivers to drive in a safer and greener (i.e., more environmentally friendly) manner through on-board advice and post-drive feedback. Seppelt (2006) applied ecological interface design (EID) to create a visual representation of Adaptive Cruise Control (ACC) behaviour. Jenkins (2007) used the first steps in CWA and developed a new approach to designing lateral collision warning systems.

The driver could both be overloaded with information that is not adequate for a specific situation but also lack information that is needed in relation to the driving task and individual driver goals (Salmon, 2007). A WDA could potentially identify the information needed for the driver to achieve the different goals.

Purpose

The purpose of this study was to identify ways to support problem solving and decision making in a driving information context and study gaps, overlaps and strong and weak relations between the purpose of the components and the component in order to improve future driving information.
METHOD

Work Domain analysis (WDA) of Driver Information system

Naikar et al (2005) provides several steps to create the boundaries for the CWA. These steps have been used and are described briefly below.

The study was performed during the spring and summer 2008. Researchers from Luleå University of Technology and Volvo Cars as well as members of a Driving Information project were involved in the project. Researchers from Brunel University, UK, provided experience from other WDAs. The main work was done by the author. The budget was limited to the budget for the researchers and to the product development projects at Volvo Cars.

Driver information can be received in many ways e.g. traffic signs, traffic message channel (TMC) etc. However, this study is limited to what a private car manufacturer could do to provide different kinds of information. The system is defined as “Private car driver information system”. Private car is defined as a car that is used in a non commercial way, for instance a taxi would not be classed as a private car. However, the car could still be owned by a company. Driver information system means that the main purpose of the system is to support the driver's goals e.g. navigates or maintains speed but also being environmentally friendly etc. It should also be stated that driver information is not only limited to within the car. Before and after driving is also included.

Most of the information needed came from the research team members. The research team members have a wide experience of driver information systems. Volvo Cars strategy documents were also used when discussing the Functional Purpose (FP) of the system. It could therefore be argued that the FP's weight could be different between different manufacturers depending on the ideology within the company.

Several iterations were performed with e.g. focus groups and interviews to create links between the FP and the PO but also discuss and describe the strength of the links.

The Abstraction Decomposition Space (ADS), described by e.g. Naikar et al. (2005) was limited to complete system. Of course it would have been possible to further break down the Systems into sub-systems and components. However, since the purpose of this study was to study gaps, overlaps, strong and weak relations between the purpose of the system and different old and future functions it was necessary to keep the level of detail low.

Abstraction hierarchy

The first step in WDA is to create an Abstraction Hierarchy (AH). There are five levels in the abstraction hierarchy:

1. The functional purpose (FP) of the system is the reason why the system exists.
2. The Abstract Function (AF) is the criteria that can be used to judge whether the system is achieving its purposes.
3. Generalized function (GF) is what functions are required to achieve the purpose of the work system
4. Physical function (PF) is the systems functional capabilities and limitations.
5. Physical object (PO) is the resources of the system.

After the decomposition an analysis was done by following the different links between the Functional Purpose (FP) down to the Physical Form (PFo). Performing such an analysis was very time consuming, although very interesting, and revealed several weaknesses in today's driving information. This created ideas of how to improve future driving information.

RESULT

Functional purpose - the overall purposes of the system and the external constraints on its operation

In the study by Salmon (2007), three Functional purposes (FP) for a road transport system were found: Safe, efficient and accessible mobility. In the present study a few more purposes of private car driving information was identified.

- Safe
- Legal
- Efficient
- Environment friendly
- Enjoyable

These are presented in figure 1-4 in Appendix 1.

Below, the most interesting findings from when the functional purposes were decomposed and analyzed are presented. The functional purpose and the abstract function are presented together with a background of the problem, state of the art and finally the possible design implications. The decompositions are shown in Appendix 1 which describes how Safety, Legal, Environment friendly and Efficient were decomposed. When decomposing such a complex domain as driving information several of the functions on different levels share purpose. One example is speedometer that both serves as a tool to keep legal speed (FP Legal) but also as a tool to see how far you can travel in one hour (FP Efficiency). In order to decrease complexity each functional purpose has been extracted from the complete WDA and is presented separately.

Functional Purpose: Safety

To drive safely is maybe the most important purpose of
driver information. Safety was decomposed into: Friction, Energy exposure, Increase time to impact, Maintain lateral and longitudinal distance, Encourage low risk behaviour, Support safe route, Reduce accidents due to technical errors and Support choice of transportation.

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Friction. The friction between the road surface and the tyres is one of the most important things when it comes to safety. Today's cars are mainly equipped with an outdoor temperature display and a symbol that shows if the temperature is somewhere between +2 or -2 degrees Celsius. Often the symbol is a snow flake. Another way to describe slippery road condition is to show that the ESP or ABS system has been used by showing a symbol of a sliding car (ISO 2575). When benchmarking different cars it was found that sometimes the snowflake became red if the temperature was within the interval, hardly a good way to illustrate slippery road condition. Neither is there any information about stopping distance or information if the driver enters a curve at too high speed for current road friction.

Design Implications. Introduce road friction displays and curve over speed warnings related to friction. Another example of Knowledge based support could be to provide the driver with information about slippery road condition before leaving home in order to improve planning.

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Energy exposure. Energy exposure is the cars kinetic energy. The kinetic energy will, in a collision, be transformed to mechanical energy that collapses the body of the car. The only thing that describes the energy exposure in today's cars is the speedometer. The Energy of the car is related to the mass and the square of the speed (E=mv^2/2). If the driver is mental arithmetic, he can calculate the energy using the formula and then understand that if the speed is doubled the braking distance or crash violence is quadrupled. Some of the cars have a non-linear scale with smaller steps on the higher speeds (probably in order to squeeze in higher top speeds in the scale). From an energy and brake distance point of view it should be the other way around. Another way to avoid energy exposure is to avoid accidents by staying away from dangerous roads. As far as the research team knows none of today's navigation systems provide road accident data or the possibility to optimize the trip from a safety perspective (Today, mainly shortest and fastest trip are included).

Design implications. Introduce Brake distance displays, introduce information about accident data and add the possibility to optimize the route from a safety perspective (i.e. avoid roads with bad accident statistics)

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Increase time to impact. If the time is long enough between the car and the obstacle there is more time to prevent a collision. Most cars do not have adaptive cruise control (ACC), distance warning or Forward Collision Warning (FCW) systems.

Design Implications. One solution is of course to introduce Advanced Driver Assistance Systems (ADAS) such as FCW. However, better strategic planning would most likely also affect tactical and operational behaviour (e.g. Michon, 1985, Hollnagel, 2005). One solution could therefore be to provide pre-trip functions such as estimated time of arrival to most common destinations such as work. This can hopefully make the driver start the trip earlier and therefore be less stressed.

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Maintain lateral and longitudinal distance. If the distance is big enough between the car and the obstacle there is more space to prevent a collision. This is off course related to "Increase time to impact". As described above most cars do not have ADAS. There are also few cars with systems that inform the driver about distraction or driver alertness. However, some systems exist. One example is Volvo Cars Intelligent Driver Information System (IDIS) that reduces distraction/workload by blocking some information in complex driving situations.

Design implications. See Increase time to impact above.

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Encourage low risk behaviour. Several studies (e.g. Summala, 1996) describe risk behaviour as a large safety factor. Behavioral adaptation due to over trust is established (Hoedemaeker & Brookhuis, 1998). None of the systems today provide feedback, information or anything else that could calibrate drivers' behaviour with the real risk. Education of drivers does mainly occur once in the beginning of the career as a driver.

Mental elaboration regarding personal driving behaviour may well have a role to play in promoting a more cautious driving style among young male drivers (Falk, 2008).

Design implications. Introduce driver Coach to Educate how to drive safely. Give feedback of how the driver performs. Show ADAS system status to calibrate the trust of the system with the function. How mental elaboration could be implemented in cars is another question not dealt with further in the present paper.

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Support safe route. Some roads are safer and more secure than others. The research team does not know of any "Safe" or "Secure" options in today's navigation systems.

Design implications. Introduce an option in the navigation system that calculate and show the safest or most secure route. A suggestion is to also include accident data in the route calculation algorithm.
Reduce accidents due to technical errors. Technical errors occur. However, when an error occur it is important that the driver acts correctly. The systems in the car must support correct action. The driver gets information about what is wrong and sometimes also what to do e.g. “Engine Failure - Stop Safely”. However, there are several examples of drivers stopping at the highway with the “Low Washer Fluid Level” telltale highlighted. There is no training of what the symbols mean or what to do if something happens. Over trust or under trust could also affect the safety effect of ADAS.

Design implications. Give better advice of what to do when systems fails. Use the team player approach to reduce automation induced errors such as under- and over-trust described by e.g. Davidsson (2008).

Support choice of transportation. Different types of transportation have different safety levels. Information about the safety of a particular type of transportation could be acquired on the internet or elsewhere.

Design implications. It would be rather controversial to suggest that private car should supply the driver with information about the safety figures for different types of transportation.

Functional purpose: Legal

It could be argued that “Legal” could have been included in ”Safe” since many of the regulations are aimed at safe driving. On the other hand some of the legislations also aim to make traffic flow smoother and reduce fuel consuming, etc. Legal has therefore its own functional purpose. Legal has been decomposed into: Reduce penalty cost.

Reduce penalty cost. Breaking traffic regulations could be either a violation or an error. The first step in finding out if it is a violation or an error is to ask: Was there a prior intention to commit this particular violation? If the answer is no, we can assign the violation to a category labelled erroneous or unintended violation (Reason, 1990). By bringing information into the vehicle and keeping it visible for the driver for a longer time than it takes for the car to just pass the traffic sign, it may be less likely to commit the category called error. Some speed keeping systems has been tested. One example is a large scale project in Sweden called ISA (Intelligent Speed Adaptation) by the Swedish road authority.

Design implications. Inform or restrain the driver from committing violation or errors. This could be done with a traffic sign display or a speed limiter connected to current speed limit.

Functional purpose: Efficient

Efficient driving means that time and cost are reduced as much as possible. Of course, this is closely related to environment friendly driving due to e.g. carbon foot-print. However, since things such as service cost, service interval etc. could not be included in that category, it needs to be separate. Accessible (Salmon, 2007), which means that the car is available when needed, is included in this FP.

Reduce cost (Service spare parts etc) Cost could be reduced by avoiding accidents (See safety). Cost could also be reduced by avoiding expensive effects of technical failure.

Design implications. Information about how much money could be saved by following the service interval could be provided. Today, service is mainly a cost for the owner of the vehicle.

Support choice of transportation. The choice of transportation affects the cost. The choice of transportation is influenced by several things. To mention a few: Number of travellers, distance, luggage or purpose of journey and accessibility. Today this information can be gathered e.g. from the internet.

Design implications. From a driver perspective it could be interesting to compare the different ways of transportation from a cost perspective. However, it is not likely that this information could be provided by the car manufacturers (E.g. “Go by train”).

Reduce fuel consumption. Reducing fuel consumption will of course reduce cost. The question is how this can be achieved by driver information. Today’s driver information mainly provides information about fuel level, current (econometer) and average fuel consumption and distance to empty. Some people use the tachometer to change gear at correct rpm. Some companies, including manufacturers, give courses on how to drive more efficiently.

Design implications. Introduce driver coach to provide education on efficient driving and give feedback on fuel efficiency performance.

Reduce time on road. If the car is on the road for a shorter time and still fulfils transportation needs it is more
Design implications. Driving information system could provide the driver with data about what is going on ahead without entering a destination. The time on the road could also be reduced by better planning e.g. leave home when there is less risk for congestion. It can be suggested that this information could be provided by internet and within the vehicle.

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Functional purpose: Environment friendly

This FP aims to give as small a negative impact on the environment as possible, e.g. carbon footprint. The FP could also include other chemicals that are contaminating the environment or even other aspects such as noise. Environmental Friendly was decomposed into: Reduce CO2 and Reduce polluting emissions and local environmental impact.

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Reduce CO2. Perhaps the hottest topic of the moment is carbon footprint. Is there a way to reduce carbon footprint by using driver information? Some cars have a gauge for present and average fuel consumption. The fuel consumption (for diesel and gasoline) is directly proportional to CO2 emissions. A few of the car manufacturers provide information about at what RPM it is least polluting to change gear, so called gear change advice. However, the execution is rather related to torque than to carbon footprint. Some companies and car manufacturers provide green driving courses and it is also included in some driving schools.

Design implications. There is a great potential to improve green driving by providing driver information. Internet can both help the driver to improve planning and also, which may be controversial for the car manufacturer, help a traveller to select a less polluting alternative. The potential of coaching is high (Walker et al., 2008). Could a green driving coach improve green driving by providing feedback and advice about how to drive more green? Another way to improve and change behaviour is by providing a game, so called edutainment. Feed forward information such as information about e.g. energy exposure or brake stop distance.

Most navigation systems in today’s navigation systems provide the possibility to change between fastest and shortest route. As suggested above, why not introduce the greenest route?

***

Reduce Polluting emissions and reduce local environmental impact. This Abstract Function has almost been forgotten in the CO2 debate. However, chemicals, dust, noise etc. is an environmental problem as well. No cars seem to supply this abstract function.

Design implications. Most settings in today’s navigation systems provide the possibility to change between fastest and shortest route. As suggested above, why not introduce the greenest route.

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Functional purpose: Enjoyable

The reason why “Enjoyable” is included is that more and more of consumer products have more dimensions than just functionality. The emotional part of a system also needs to be considered and this is taken care of here. A very important issue is for example that a car not only needs to be safe, it also needs to feel safe. These two attributes can counteract. On the other hand a car or an in-car system that feels a lot more safe than it is may induce risk behaviour, e.g. research has shown that drivers tend to misuse the increased safety margins that ADAS create by adapting their driving style. One example of this is drivers increasing their driving speed and not paying as much attention to the driving task compared to driving without ADAS (Hoedemaeker & Brookhuis, 1998). It could be argued that Enjoyable is included in the other FP’s in one way or another. For example isn’t it a “good feeling” to know that you can avoid high penalty cost by the systems in the car or isn’t it great to see that you are driving green or safe? This is emotions. The research team decided anyway that it was important to find a way to place emotional aspects and it is suggested that this will be dealt with later. This study did not further handle this FP due to time constraints.

DISCUSSION

Method

Choice of method. CWA provides a toolbox for dealing with complex socio-technical systems (Vicente, 1999). When going through the definitions of what a “socio-technical system” is and the definition of “complex” it is clear that this method could be used also for driver information. WDA has been a very useful concept in order to investigate functional content in relation to its purpose. Filling the gap between the physical function and functional purpose clarifies why or why not a function is used. For instance, that the link between speedometer and safety was weak and must somehow be complemented with information about e.g. energy exposure or brake stop distance.

Design implications. The purpose of this analysis was to study gaps, overlaps, strong and weak relations between the
The purpose of the system's different old and future functions. The WDA came up with several design implications that may improve safety, environmental friendliness etc. The analysis also made clear that today's instrument cluster does not focus directly on safety even though most of the research team had never thought of that before. It could therefore also be concluded that it is very important for design teams to know why they are designing the driving information.

During the analysis it was also found that CWA can be useful when prioritizing functions. For instance, if the vehicle is aimed for environmental driving, the links could be followed between the functional purpose and the different systems. If this is complemented with a grading system it is possible to see if a function is important or not for the functional purpose; Green driving.

Further research

The research team has identified research needed:

Context activity template. The functional growth is both a potential as described above but also a threat. A threat due to the fact that it is impossible for the driver to process all this information simultaneously. It would therefore be interesting to continue this research by adding a Contextual Activity Template (Naikar et al., 2005) which is a part of CWA step 2. This template helps to clarify which of the generalized functions (GF) are used in which context.

Importance. In order to prioritize functions it would be interesting to find a method to decompose the “importance” of the different functional purposes down to “importance” of functions. This method may then work as a tool to support prioritization of functions. Birell (2008) has made an interesting attempt.

FP Enjoyable. The FP Enjoyable should be further investigated.

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APPENDIX 1.

Decomposition of functional purpose Safety, Legal, Environment friendly and Efficient.

Figure 1. Decomposition of FP Safety

Figure 2. Decomposition of FP Legal.

Figure 3. Decomposition of FP Environment Friendly.
Figure 4. Decomposition of FP Efficient
Context adaptable driver information — Or, what do whom need and want when?

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A B S T R A C T
This study deals with a first step towards context adaptive functionality of a Driver Information System.
Driving a car is a complex task for which the driver needs appropriate information to fulfil his or her goals.
New methodologies enable adaptability to driver state, task, personality etcetera and also to the context.
The aim of this study was therefore to investigate what information people perceive that they need and
want from the car in different contexts and to what extent there is consensus about the function. A
new methodology was developed, and 33 private car drivers were interviewed and asked to rate a
number of possible abstract functions in a car in different contexts.

1. Introduction
In the near future it will be necessary and expected, as well as
possible to better support the driver in driving more safely, envi-
ronmentally friendly, efficiently (cost and time) and legally,
through new technology such as displays, sensor and connectivity
(Davidsson et al., 2009). One of the most important and best
available ways of doing this is probably to provide the driver with
appropriate information.

An additional purpose of driver information is to support emotional aspects (comfort, perceived control, fun etc.) (Davidsson et al., 2009), meaning that some of the functions in the vehicle exist also or just because drivers perceive a need or desire for them. They may find that the function is not needed for rational reasons but that it is “enjoyable” or “fun” or perhaps because it is “used to be there”.

The real “need” of information may be most easily found in driver models such as the strategic, tactical and operational level of control model by Michon (1985), the SRK taxonomy by Rasmussen (1986) or collected from experts such as human factor experts, crash statisticians, safety analysts, green driving or engine experts. However, if a function is given low priority because it is not really
needed from an expert point of view, the design or functionality
may be experienced as poor. Furthermore, a function perceived as un-needed but that, from an expert’s viewpoint, is important may require more design effort to motivate it.

These purposes, technology push and the fact that future cars have access to a huge amount of information gathered by car to car (C2C) or car to infrastructure (C2I) can, if not designed in a careful manner, result in a functional growth that may reach beyond drivers’ capability. Showing all the information simultaneously would probably create distraction and inattention and make driving less safe, less environmentally friendly and so on because of visual, manual or cognitive distraction. (For a definition, see for instance Regan et al., 2004.)

One of the problems with previous and most of the current driver information system hardware is that it is inflexible. However, new display technology has enabled adaptability (and flexibility), and it may therefore be possible to better adapt to drivers’ needs and desires. Alfredson (2007) suggests that ideal system development should include a dynamic adaptation of interfaces to different input factors, such as current vehicle status, situational conditions and contextual prerequisites as well as the individual’s status, operator performance and historical behavioural data. For instance, a tired driver and an alert driver, a daily trip to work and a holiday trip, a worn car and a new car and drivers with long and short response times may need different information. This dynamic adaptation may either be performed automatically by a dialogue manager with an increased risk for automation induced errors such as mode...
confusion and increased mental workload, or manually through interaction with the system with an increased risk for visual and manual distraction (Davidsson, 2009).

The scope of this study was therefore to take a first step towards dynamic adaptation by studying if and how different contexts require different information. For instance, how needed or wanted is a speedometer when the car is parked in a garage? A natural starting point is therefore to study how context can govern driver information functions. Another issue is of course the level of consensus among drivers about what information should be available and when it should be available.

The purpose of this study was therefore to investigate:

- whether drivers want or have a perceived need for different functions in different contexts (Q1),
- what information different drivers perceive to be needed and wanted in different contexts (Q2),
- the extent to which there is consensus about each function (Q3),
- And to illustrate and make understandable the functions in the different contexts (Q4).

2. Method

2.1. Approach

The study was a combination of an interview and a rating of functions. The purpose of the interview was to try to make the participants think beyond today's design of cars and to gather data for an understanding about how people think in different contexts.

The numerical data in this study were not used for significance testing but rather for the purpose of analysing the function's levels of importance and level of consensus among car drivers.

The reason for this approach was that, when working with functional models, it is necessary to have an understanding of how people think, rather than studying only what functionality they have today or what the functionality currently does. The intention of the numerical data was instead, in conjunction with the interview, to form an answer to the research questions.

2.2. Participants

Thirty-three Swedish private car drivers, 14 men and 19 women, participated. The participants were on average 42 years old; the minimum age was 20 and maximum age 69. The drivers' experience spanned between the categories of beginners to experienced drivers (Michon, 1993), and they were recruited in the Gothenburg region of Sweden.

The different contexts and functions were decided in a group discussion by five Safety and Human Machine Interaction (HMI) experts at Volvo Car Corporation and Luleå University of Technology. The experts were also used when developing the Context Function Matrix (CFM), heavily inspired by the Context Activity Template (CAT) by Naikar et al. (2005) (see Appendix 1). The CAT is included in the second level in Cognitive Work Analysis (CWA) (see for instance Vicente, 1999), which is called Activity Analysis.

2.3. Driving contexts

The criteria for grouping contexts were threefold. First, the context groups should be easily distinguished from each other. Second, they should cover a whole “typical” trip from door to door. Third, they should offer some kind of information needed in the context to support the purposes mentioned in the objectives (not only safety).

The following context groups were established (a context group has different locations but similar road type).

- Before/After: Before-going to-entering the car/post driving.
- Car parking: When parked, in a car park or in a garage, looking for a parking place.
- City crossing: Intersection, traffic light, left turn across path, straight crossing path, roundabout.
- Highway crossings: Intersection, red light, left turn across path, straight crossing path, roundabout.
- Straight highway driving: Drifting, lane change merge, negotiating a curve.
- Queue: Driving in a queue.

2.4. Apparatus

Nine pictures (3 × 3 matrix) illustrating one context group were displayed on a paperboard. Among the different participants, the pictures were randomly mixed on the board to avoid order effects. The pictures showed different viewing angles such as from inside the car and a bird's eye view. See Fig. 1. The contexts “queue” and “before/after” driving were found difficult to illustrate by pictures.

Instead, written text was used.

2.5. Simulation interview

A simulation interview was conducted, inspired by the Applied Cognitive Task Analysis (ACTA) method (Müller and Hutton, 1998). The simulation interview is a walkthrough, a mental simulation of driving in or through the specific context, after which the participants are asked to think of what they do, how they do it, what they find difficult and what they feel. The interview was not biased towards safety or green driving or any other attribute.

Most of the participants were interviewed in two contexts but some in only one, due to time constraints. There were ten participants in each of the six contexts, which gave a total of 60 interviews. The duration of each interview was in general between half an hour and 1 h.

2.6. Representation of functions

Davidsson et al. (2009) decomposed the functional purpose of driving information by using the first step in Cognitive Work Analysis (CWA) called Work Domain Analysis (WDA) described in for instance Vicente (1999). This decomposition was used to define the functions, and the second lowest level of abstraction, called physical function, was used. The 70 physical functions can be found in the FCM in Appendix 1.

2.7. Grading

A grading scale from 1 to 5 was used. (1 = not important, 5 = very important). In addition, a “waste bin” was provided for functions not applicable, inappropriate or considered dangerous.

2.8. Procedure

Each interview followed the procedure described below in which numbers 1–4 represent the simulation interview.

1. The participant sat down in front of the board with pictures.
2. The participants were given instructions:
   a. Look at the pictures on the board (see Fig. 1) for a few minutes.
   b. Think of what you are doing in a context like this.
   c. Think of what is easy or hard for you in this context.
   d. Consider that the traffic flow, road and time could be different from what you see.
   e. Can you divide what you are doing into phases, going from the red to the green dot (provided on the pictures)?
3. The participants were left alone for 5 min.

4. They were asked to describe what they did in a context like this. Notes were taken.
   a. Describe what you do in this type of context and what strategy you have.
   b. What is important for you in this type of context?
   c. What is the most positive thing about driving in this type of context?
   d. What is the most negative thing about driving in this type of context?
   e. Can you name any information that you would like to have from the car in this type of context?

5. Grading of physical functions. Notes were taken.
   a. The participants were asked to "grade the function from 1 to 5, where 5 is very important and 1 is not important; if the function is not applicable, inappropriate or dangerous for the context, put it in the waste bin".
   b. The participant was given instructions to say the name and number of the physical function, to think aloud and to ask questions if the function was not understood.
   c. The participant took a card on which the physical function was printed from a randomly mixed stack of cards, read the physical function and the number aloud (then often looked at and browsed the pictures) and decided which grade to give the function. The card was put in a cup below the pictures (see Fig. 1).
   d. If the participant put a comment, notes were taken.
   e. The participants were then shown gratitude for their participation. No monetary compensation was given.

2.9. Illustrating the functions in the different contexts

After the interview, the data were gathered and the average, standard deviation and percentage of waste calculated (See a few examples in Table 1). The different functions were then arranged in the CFM as described in Fig. 2.

3. Results

3.1. What information do different drivers need and want in different contexts?

3.1.1. Grading of physical functions

Because of the large number of functions (70), Table 1 shows only a selection of the grades from the grading exercise. The complete table of results can be acquired from the author upon request.

3.2. Interpretation of grading and free text

Not surprisingly, the results indicate that drivers want or need different functions in different contexts. One way of analysing the data is to follow the function through the different contexts, for instance, the function "Show where the roads are heading in the next intersection" (See CFM in Appendix 1 or Fig. 2).

Before and after driving, this information is of little use to the driver (M = 1.3, SD = 0.6, W = 70%). In the car park or in the garage, the drivers start to prepare for their departure. Some found the information interesting, but most believed that it was of no help (M = 2.8, SD = 1.3, W = 50%). At the highway crossing, the grades indicate both...
that drivers wanted and/or needed the information and that there was consensus about it (M = 4.2, SD = 1.3, W = 10%). On the straight highway, the driver again found the information less important (M = 2.7, SD = 1.1, W = 10%). If the driver ended up in a queue, the grading increased somewhat again (M = 3.1, SD = 1.4, W = 10%). From the notes taken, it is understood that the driver wants to solve the queue problem by finding another route to the destination. At the city crossing, drivers again found this information useful (M = 3.8, SD = 1.2, W = 0%), as in the case of the highway crossing.

The grades (M = 3.2, SD = 1.4, W = 28) for all contexts for this particular function reveal nothing more than that it is rather useful for these particular contexts since the contexts are not weighted and all possible contexts are not included in the results. However, if the standard deviation was lower, such as in the case with the function “Show that there are queues on the way to the destination” (M = 4.0, SD = 1.0, W = 10%), it could be interpreted that the function is useful in more or less all contexts.

These are a few examples, but the way of analysing a function may be the same for all.

### 3.2.1. Before and after driving

Before driving, functions of a more strategic character are graded high: “warn for slippery road conditions”, “show outdoor temperature”, “warn for slippery road conditions on the way to the destination”, “show fuel level”, “show distance to empty tank”, “show alternative roads to the destination”, “show information about dangerous roads”, “show estimated time of arrival”, “show that there are queues on the way to the destination”, “show recommended speed due to road conditions, visibility” and “show tire pressure in the different tires”.

However, the consensus is low for many of the functions. For instance, “show recommended speed due to road conditions” was graded to be important, although three out of ten participants stated that they did not want the function at all (M = 4.2, SD = 0.4, W = 50%).

On the other hand, functions such as “show coming traffic signs”, “show that you are unintentionally changing lane”, “warn if the car enters a curve at too high a speed”, “show if there is a traffic light soon”, “show other cars in an intersection”, “show when it is permitted to take over”, “show road grip in relation to how much you turn” are rated very low with a high consensus. These are mainly tactical and operational, which is of course less use in this context.

The open end answers such as “before long trips”, “when planning a trip”, “plan when to fill up the tank”, “plan when to eat” and “before you go” together with the grading reveal that this is information that is used for strategic decisions and long term planning. In some cases, the comments also deal with feedback from the car; for instance “compare how fast you drove at permitted speed” or “good to have statistics afterwards”.

### 3.2.2. Car parking

In the case of parking, information close to the vehicle is more interesting to the driver. Functions such as “show a top view of the car and its close proximity”, “show free parking places” and “show near view behind the car” are among the top grades. These functions can be considered tactical and/or operational. There is consensus about the first two functions mentioned above. However, the latter shows a lower consensus. Some mentioned that they “wanted to see for themselves”, which may explain why they did not want information from the car. Interestingly, speed came in 26th place, although with a low consensus.

“Lap time”, “show cruise control set speed”, “ability to watch movie”, “show when it is permitted to take over”, “show engine oil temperature” and “show average speed” were given the lowest scores but had a high consensus.

Open end comments such as “important to see what the time is”, “plan the trip” and “plan for slippery road conditions” indicate that the functions should primarily be useful before strategic decisions. Together with the high grades described above, this shows that the most important information is both strategic and operational.

### 3.2.3. Highway crossing

In a highway intersection, the drivers want and need functions such as “show if there are cars in the blind spot”, “warn for slippery road conditions”, “improve night vision”, “warn if the car enters a curve at too high a speed”, “show where the roads are heading in the next intersection”, “show recommended speed due to road conditions, visibility etc.”, “inform that you are driving too close to the vehicle ahead”, “what the next intersection looks like” and “show alternative roads to the destination”. It seems that the driver needs and wants information on all three levels when approaching an intersection. There was high consensus among the participants about which information is useful and desired.

“Ability to surf on the Internet”, “show free parking places”, “show engine oil temperature”, “show engine oil pressure”, “lap time”, “show start time for parking heater” and “remind that the car needs regular service” received the lowest grades. As among the top graded functions, there is a consensus that these functions are of less use when driving in intersections.

“Stressful to find the right way”, “Great, this is where accidents happen” and “Affect my speed” indicate that the information needed is a more tactical character than for parking and for before and after driving.

### 3.2.4. Straight highway driving

The functions are mainly strategic or tactical. “Show speed” was given the highest grade. Functions such as “warn for slippery road conditions”, “improve night vision”, “show fuel level”, “warn for slippery road conditions on the way to the destination”, “warn for being distracted (e.g. looking away for a long time)”, “show alternative roads to the destination (in the case of queues or accidents)” and “show recommended speed due to road conditions, visibility etc.” were also given a high grade. There was high consensus among the drivers that these functions are important.

---

**Table 1**

| **Before and after driving**    |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Car park                        | 1.0 | 90 | 3.1 | 5.0 | 3.0 | 4.1 | 3.1 | 5.0 | 3.0 | 4.1 | 3.1 | 5.0 | 3.0 | 4.1 | 3.1 | 5.0 | 3.0 | 4.1 | 3.1 | 5.0 | 3.0 | 4.1 | 3.1 | 5.0 | 3.0 | 4.1 |
| Highway crossing                | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 |
| Straight highway                | 6.7 | 3.2 | 30 | 4.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 | 40 | 3.2 | 1.7 |
| Queue                           | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 | 40 | 1.1 | 0.7 |
| City crossing                   | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 | 40 | 2.4 | 1.4 |

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The lowest rankings were given to “show engine oil temperature”, “learn the car’s different functions and systems”, “show start time for parking heater”, “show how fast the car accelerates”, “ability to watch movie” and “ability to play games”. The consensus for these functions was also rather high.

3.2.5. Queue

A queue is different from the other contexts. It could perhaps better be described as a situational condition rather than a context. Nevertheless, the most important functions while driving in a queue are: “show alternative roads to the destination”, “show that there are queues on the way to the destination”, “show that an accident has occurred on the way to the destination”, “show a map of where you are”, “show the current time” and “show where the roads are heading in the next intersection”. It seems that the drivers need strategic information and support in order to solve the problem themselves.

Interestingly, functions such as “ability to play games”, “ability to surf on the Internet” or “ability to watch a movie” were rated rather high. However, there were high standard deviations, which indicates low consensus.

The functions that were graded lowest were mainly related to speed, which gives information about something that the driver in fact lacks. These were functions such as “warn if the car enters a school/Straight highway driving”, “show how fast or slow you have to drive to get a green light”, “show information about speed cameras”, “show cruise control set speed” and “show how fast the car accelerates”. Speedometer came in 24th place.

“Something to entertain myself with”, “at least something to do” and “something to play with” show that drivers can accept some functions that they normally would not.

3.2.6. City crossing

“Show if there are cars in the blind spot”, “improve night vision”, “show alternative roads to the destination”, “show that an accident has occurred on the way to the destination”, “show that you are driving close to a school”, “help recognize other nearby vehicles” and “warn for slippery road conditions” were functions that received high grades. Similar to the case of highway intersections, the consensus on the functions is high.

There was a high consensus about the lowest grades: “show engine coolant temperature”, “show oil level in engine”, “show engine oil temperature”, “measure time”, “show travel distance in total” and “show engine oil pressure”.

3.2.7. Notes

Notes were taken during the grading. These notes help to explain why the participants gave the grade they did and the preferred source of the information: car, driver, road authority etc. The notes can be acquired from the author upon request. However, a few examples are provided below.

Example: Function/Context: “Note”

- Show fuel level/Before and after: “If you have to leave earlier, for planning”
- Show that you are close to a school/Straight highway driving: “There are signs about this” (indicates that the participant prefers a sign instead of in-vehicle information)
- Show information about dangerous roads/Straight highway driving: “Want to see in reality” (indicates that the participant prefers to see for him/herself rather than using in-car information)

3.3. A metaphor

When looking into the data the research team recognized a pattern. This pattern resulted in an easily understood metaphor, to be further developed and validated, for how the participants graded the functions and can be seen as a “zoom lens” (See Fig. 3). Before, when planning the trip, the driver zooms out to make strategic decisions about the trip. In the parking area, the driver zooms into the closest
proximity of the vehicle. Then, on the highway, the driver again zooms out. What is going on next to the car is not important. When the driver approaches an intersection, the tactical positioning is more important and the driver zooms in again but not to the closest proximity.

4. Discussion and conclusions

4.1. Discussion of the results

The first research question was whether drivers want or have a perceived need for different functions in different contexts (Q1). The interviews, function grading and open end answers in the study gave an indication that drivers have different perceived needs and desires in different driving contexts. A function, very important in one context, can be of no or little use in another context. An interview and a rating of abstract functions were carried out to investigate what information different drivers perceive to be needed and wanted in different contexts (Q2). The ratings gave a hint about what functions are needed or wanted and the standard deviation indicated to the extent to which there is consensus about each function (Q3).

A CWA was created to illustrate the information needed in different contexts in a simple way for designers (Q4). The CWA can be utilized in the design of new context adaptive driver information interfaces. For instance, in queue driving, an explanation for why there is queue may be a way to solve the problem by perhaps giving re-routing information, while speed is of less importance. Drivers also want to be able to reduce the negative effects of queuing by for instance visual entertainment.

4.1.1. Information that different drivers perceived needed and wanted in different contexts

It is indicated that there are differences between different persons’ opinions about what or who should provide the information for some of the functions. Should it be the car, the road authority or the driver him/herself? Some wanted for the most part to see for themselves and did not believe that a system could help them, and others preferred systems for almost everything. Perhaps different ways to enable these kinds of functions for a driver, ranging from option at purchase to a check box in the settings menu, can be an appropriate solution.

This phenomenon may be illustrated by the function “help to recognize other nearby vehicles” in the “highway crossing” context. The function received a high grade, a high variance and two participants put the function in the waste bin (M = 4.0, SD = 1.1, W = 20%). It is likely that this function may help some, annoy some and even be found inappropriate by others.

One explanation for this difference between participants may be found in the terminology for “locus of control” (Rotter, 1966). Locus of control is defined as a personality attribute reflecting the degree to which a person generally perceives events to be under his or her own control (internal locus of control) or under the control of external forces (external locus of control). Research has shown that locus of control is one of the most crucial psychological factors determining drivers’ acceptance of new in-vehicle technologies (Rudin-Brown and Noy, 2002).

When designing context adaptive information systems, it is important also to have consensus about the contexts. In this study, before and after driving were merged into one context. However, the results showed that the information wanted and needed before driving and after driving is sometimes completely different. This made it difficult for the participants to give a grade that was equal for both before and after. Consequently, the participants used different strategies when they graded functions, such as “a trickage between the two” or “a five – five before”. This indicates that the context is “weak”, and a split of the context may be suggested.

4.1.2. Usefulness of the results

The usefulness of the outcome may be divided into two parts: the result in itself and the method. More available information and a higher demand on performance require, and flexible display technology enables, context adaptive driver information. The results can be used as a guideline for design of context adaptive driver information systems or for optimization of display space. For instance, functions that are perceived to be less important can be made less salient and those that are more important more salient in different contexts. The results, and in particular the grades, could possibly also be used as a weight when evaluating future adaptive information systems. For instance, a system that has a high score for the function “show speed” in a parking context still gets a weighted score that is low.

In an adaptive driver information interface, when deciding how a function should be activated (automatically or manually) and if the design should be individualized, the system designer may look at the standard deviation. A large standard deviation can indicate low consensus about the function and, consequently, some of the drivers may be surprised or annoyed by receiving this information automatically. Furthermore, a large standard deviation may therefore also put forward that the design should be individualized.

The method, changing the level of abstraction in both context and function, was an attempt to make participants think beyond the common functions and specific contexts that may be further developed and used in the development of, for instance, future In-Vehicle Information Systems (IVIS). Methodological considerations are further discussed below.

4.2. Methodological considerations

It was necessary to be somewhat creative in designing this study in terms of the balancing act between being too user centered and being too expert oriented. The following section considers the challenges and describes the solutions.

4.2.1. Data collection

A previous CWA was used to identify and formulate the functions in the interview. Normally, when performing a CWA, the designer of the system has to move outside the user community to get input for the design (Burns and Hajdukiewicz, 2004). The idea is to provide the user with a greater level of control of the data collected came from users solely via, for instance, surveys, as in a User Centred Design (UCD) approach. In this study, the safety and HMI experts defined the different physical functions and the different contexts, but real users were used to grade and give comments. The reason for this mixture was that real users may have more than rational reasons, wants,
perceived needs or desires, for ranking a function high or low, while experts are perhaps better at judging real needs. This dimension needs to be considered, since private cars are consumer products and purchase involves emotions that are not always rational.

4.2.2. Simulation interview

To make the test participants better decision makers, it was important to support them in identifying central attributes, such as safety or environment friendliness (Wickens, 1992). Furthermore, it was important to make the participants think of what they do, how they do it, what they find difficult and what their feelings are, to make the grading of the functions better.

4.2.3. Driving context

There are of course more possible contexts than the few that were chosen and, depending on the use of the results, other contexts could have been included. This study’s contexts were decided by HMI and safety experts, and the contexts are thus possibly more important from a safety perspective. However, the pictures on the board were as unbiased as possible and did not show anything particularly problematic or hazardous. The reason for this was that the study was about the drivers own experience. For instance, if a picture was shown of someone in an accident, the participants may have increased their acceptance for an accident avoiding system.

4.2.4. Participants

As this was a first study regarding context dependent information it was natural to start in Sweden. However, the between subjects design allow for other contexts and other regions.

4.2.5. Apparatus

The reasons for showing pictures, and showing them simultaneously, were threefold: first, in order to get a grading from a generic context rather than from one specific one, it was necessary to present several examples of the family of one context; second, we wanted to avoid serial position effects (e.g. Wickens, 1992) that may occur if the contexts are presented in sequence, such as in a movie; third, the pace at which a driving task is performed may be important. If the participant is presented a movie in which someone else is driving, the pace could be different from the participant’s own, and this may well have an effect on the result.

There are indications that this worked as intended. The participants browsed the board and did not seem to favour any of the pictures. They discussed the whole sequence of the context, they mentioned events in their own experience that could be applied to the pictures and they discussed their own pace in similar situations.

4.2.6. Function

An important challenge was how to illustrate the functions to reduce bias from well-known functions. An approach was needed that gave the less used, very new or more complex functions a reasonable chance. Shifting the representation from a low, detailed level (physical form) to a higher level of abstraction with less resolution can make complexity look simpler. Put metaphorically, moving up one or two levels allows drivers to “see the forest for the trees” (Vicente, 1999). In addition, when creating a CAT, the abstraction is on the general function level (GF). However, this level seemed to be too abstract for the users to understand.

It also seemed that the participants lost their ability to judge their “wants” the more abstract the function became; they became experts. The trade-off between being too abstract to be understood, bias of well-known systems and how the CAT is usually carried out amounted to choosing the abstraction level, physical function (PF).

Using the abstract level of physical function rather than physical form or general function also seemed to have worked as intended, but it is difficult to see how well. One indicator was that, instead of just grading the function without much thought, the participants gave the impression of thinking twice before giving their grade and they moved sometimes up and sometimes down one level of abstraction, just as intended. A second indicator was that very common functions such as “show speed” showed great differences in how they were graded in the different contexts.

Nevertheless, a more extensive comparison between the two ways of presenting the functions would be appropriate.

One constraint when designing driver information is that some functions are mandatory from a legal perspective. In this study, however, participants were able to rate even “legally necessary” functions low.

4.2.7. Statistical analysis

The participants were interviewed in only one or two contexts (between subjects design). The reason for this test design was threefold: first, to keep the time spent on each interview within reasonable limits and, secondly, to be able to add contexts afterwards. Finally, the pilot study showed that participants, if interviewed in more than two contexts, also included the transition between the different contexts, which was not intended. The transition between two sets of information may be regarded as an automation challenge; this is discussed for instance by Davidson (2009).

The effect of the test design and the limited project resources resulted in a small number of participants in each context, which of course poses limitations to the statistical analysis when comparing the contexts.

4.2.8. Grading

A scale from 1 to 5 (1 = not important, 5 = very important) without a waste bin would not have worked since a function could be worse than “not important”. A function could also be not applicable, inappropriate or dangerous, and the waste bin was added for this reason. For instance, “show speed” may be considered not to be applicable before driving and after driving and “ability to surf on the Internet” may be inappropriate and dangerous while driving in an intersection.

As a consequence, the size of the population varied in almost every function, which makes it more difficult to calculate different statistical measures. However, the statistics and the open ended answers may together give an answer about whether and how well a function suits a particular context.

4.2.9. Reliability

The question “show average speed” was repeated (functions 14 and 77) to judge whether the participants were able to give a similar grade twice. The difference between the mean values is small with one exception: HC. However, this indicates that the respondents reason in much the same way. Details also reveal that only one participant had a greater difference than one grading step between the two questions in HC.

The number of respondents was limited to ten persons in each context. To validate the methodology further, it is recommended that at least one context category be repeated with a greater number of participants.

4.3. Final remark and conclusion

Driver Information that adapts to current vehicle status, situational conditions and contextual prerequisites etcetera may be a future dream. This study aimed to get beyond drivers’ current needs and describes a perhaps new approach to represent functions and contexts and a new way to grade functions. The study resulted in a context function matrix and a zoom metaphor useful for future implementation.
context adaptive driver information. The novel approach, limited number of participants, number of contexts and that the research only took place in one country implies that further research is needed.

Appendix

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References


Applying the "Team player" Approach on Car Design

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Abstract. Automation can cause problems with ‘the human factor’. One approach is to make automation become a team player. A team player agrees on a common ground, they show intention, they show reasoning, express their limits of performance and so on. This approach has been applied to adaptive driver information in the present study. Ten experts on different in-vehicle systems were interviewed. The experts found the team play approach both challenging and interesting. However, the experts also found a difficulty in combining the increased visual workload required to "be a team player" with car driving, that is already visually, manually and cognitively challenging. The experts believed that the approach described by the researchers rather described agents before they become team players than being team players. What is needed is "teambuilding"; the solution suggested is a compromise and could be described as a separate view for the above mentioned information.

1 Introduction

Whether we like it or not a lot of new information is available for the driver and there is more to come when cars become connected to the internet or other infrastructural networks. Car to car information, Car to infrastructure, as well as in-car information coming from new sources such as radars, sensors etc will most likely invade cars. The reasons for this may be to improve safety, environmental friendliness, transport efficiency and perhaps also because drivers just like the information [1]. However, it is not reasonable to show all the information from these gadgets or functions simultaneously due to visual and cognitive workload. Therefore, some car manufacturers (e.g. Volvo Cars) have introduced workload managers. So far these have been limited to reducing workload by blocking information to the driver in critical situations. The next step will most likely not only block information but also provide situation adapted information. For instance, do we really need the speedometer in the garage? Maybe a 360 degree camera would be more helpful there and, of course, vice versa on the highway. In many ways it could then be said that the car works as an agent or an automatic system that controls the information flow. In the extreme, the whole driving task may be automated [2].

Automation is very well investigated. When introducing automation one reason is often to reduce workload. However, capitalizing on some strength of automation does not replace a human weakness. It creates new human strengths and weaknesses—often in unanticipated ways [3] Stanton & Young (2000) [4] discuss driving
automation and raise issues such as trust, mental workload, locus of control, driver stress and mental representation. Norman (1993) [5] expresses that technological artifacts can enhance human expertise or degrade it, "make us smart" or "make us dumb".

It is therefore obvious that introducing automation can cause problems but what do we do about it? One way of getting away from at least some of the automation induced problems is to make automation become a friend. Dekker (2002) [6] concludes that system developers should abandon the traditional "who does what" question of function allocation. Instead, the more pressing question today is how to make humans and automation get along together. Parasuraman et al. (2008) [7] doesn't agree with much of the content in Dekker (2002) [6] but points out that he sees some value in their team play approach. Woods (1999) [8] raises several questions about automation in cockpits for aircrafts. What should we learn from the problems? Do they represent over-automation or human error? Or perhaps there is a third possibility; they represent coordination breakdowns between operators and the automation? Instead of reducing automation or designing mainly to reduce errors it is suggested that it is possible to tame complexity of a system by making the automation act as a team player. Young et al. (2007) [9] suggest that a blend throughout the driving subtasks may prove most efficient and that we are thinking in terms of shared authority, rather than either human or technological authority. Sarter (1995) [10] consider supervisory control of automated resources as a cooperative or distributed multi-agent architecture. One cooperative agent concept, "management by consent," requires that the human members of the team agree to changes in target or mode of control before they are activated. This cooperative architecture could help the people in the system to stay involved and informed about the activities of their automated partners.

In summary, when designing a joint system for a complex, dynamic, open environment, where the consequences of poor performance by the joint system are potentially grave, the need to shape the machine agents into team players is critical [11].

All of this sounds reasonable. However, the big problem is how do we create car systems that act as team players?

Klein et al. (2004) [12] outline ten challenges for making automation components into effective "team players" when they interact with people in significant ways: 1) To be a team player, an agent must fulfill the requirements of a Basic Compact to engage in common grounding activities. 2) To be an effective team player, agents must be able to adequately model the other participants’ intents and actions vis-à-vis the state and evolution of the joint activity. 3) Human-agent team members must be inter-predictable i.e. be able to observe and correctly predict future behavior of teammates. 4) Agents must be directable. 5) Agents must be able to make pertinent aspects of their status and intentions obvious to their teammates. 6) Agents must be able to observe and interpret pertinent signals of status and intentions. 7) Agents must be able to engage in goal negotiation. 8) Planning and autonomy support technologies must
enable a collaborative approach. 9) Agents must be able to participate in the management of attention and finally 10) Controlling the costs of coordinated activity.


Summarizing the ten research challenges by Klein (2004) [12] and the other researchers’ statements about how to make an agent become a team player and also adding a time line may look like table 1.

<table>
<thead>
<tr>
<th></th>
<th>Behavior as a team player</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before:</strong></td>
<td>Share common goals, Show intention, Share representation of the problem state, Directable, Negotiable, Being observable, Observe humans, Negotiable levels of authority, Future oriented</td>
</tr>
<tr>
<td><strong>During action:</strong></td>
<td>Being gentle, Not overloading, Not clumsy, What is it doing?, Negotiate, Show its limits of performance, Share representation of the activity</td>
</tr>
<tr>
<td><strong>After:</strong></td>
<td>Explain why action, Feedback, Why did it do this? Observability (including things being observed, observer, context), Change behavior after negotiation, Give humans feedback</td>
</tr>
</tbody>
</table>

1.1 Purpose

The purpose of this study was to create a starting point for making automation become a team player in a driver information context using the research about how to become a team player. The study should also serve as a way to highlight important questions when automating information flow in the vehicle.

2. Method

2.1 Participants

Two female and eight male experts at Volvo Car Corporation, Luleå Technological University and Chalmers participated in the study. The reason for having so many experts was that they were experts in highly automated systems of cars, but in different areas which may cause disparate answers. The areas of expertise were design of Active Safety systems, design of Driver Information Systems and HMI design.

2.2 Material

The experts were sent an e-mail with a scenario before the interview (See italic below). The experts were also provided a list of potential problems by automating
information flow. The problems described were over-trust, under-trust, skill-degeneration and workload when automation fails.

Scenario: "It is morning and you have just left the bed. You go down to the kitchen and take a quick look at the computer. There are no queues yet but the road condition seems to be slightly slippery. The car is filled up with fuel and doesn't need a service for a while but perhaps it is better to leave earlier due to the road condition. It may take a few extra minutes to get to work. You spread the table and start to browse through the paper. You like to take it easy in the morning. You clear the table and go to the car. Where there used to be a speedometer and tachometer there is a screen with information about the car’s status, about the same information as on the computer but in more detail. In addition you get feedback about how fuel efficient you drove last time and you are reminded to change gear earlier. You start the engine. The screen now shows a 360 degrees view around the car to make sure that there are no obstacles around the car. You reverse the car and enter the road. Now, the speedometer, a map over the area and where the roads are heading in the next crossing are shown. When you approach the crossing more details are shown and the speedometer shrinks. There is also advice that you should mind meeting traffic when turning left since many accidents have happened...."

2.3 Procedure

The Delphi [13] procedure was used. Anonymity of groups and interaction with controlled feedback reduces bias and also makes measurable feedback available.

The Delphi method first elicits judgments from experts individually; the expert then gets the judgment from the previous experts and could then re-evaluate his/her own judgment. The method was modified in the way that instead of having individual feedback sessions after all being interviewed, all experts were called to a focus group meeting.
3. Result

Table 1. is a summary of the results from the interviews. The comments are listed in order of presence (Most commonly mentioned first).

<table>
<thead>
<tr>
<th>1. How do you define a &quot;Team player&quot;?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team players achieve an improved result by working together rather than individually and have a holistic view. The team work is built on knowledge of the others and own performance limits and trusts in that each are doing their best. The team players find a pleasure in working together.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 A. Share common goals,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most of the experts mentioned a combination of different ways of sharing a common goal.</td>
</tr>
<tr>
<td>• The driver could enter a goal mode for the trip: E.g. Environmental friendly, safe, sporty or efficient.</td>
</tr>
<tr>
<td>• The system should understand the goal for the trip and adjust the information thereafter. This could be done by comparing present state with a database. E.g. Time, location but also dynamic information such as driving behavior or looking at the response of information (e.g. discard).</td>
</tr>
<tr>
<td>o &quot;A real team player knows what I want&quot;.</td>
</tr>
<tr>
<td>o It should be set at the car dealer depending on personality.</td>
</tr>
<tr>
<td>• The information should be good as it is (One mentioned 95%) but could be adjusted in a menu or similar.</td>
</tr>
<tr>
<td>• It is not a team work if the driver is the only one in charge.</td>
</tr>
<tr>
<td>• Another mentioned that some things could be predetermined e.g. that the driver doesn't want to crash.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 B. Show intention, Future oriented</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Some suggested that next upcoming mode should be visible.</td>
</tr>
<tr>
<td>• The experts accepted different levels of intrusiveness: By looking at it rather than highlighted for attention / It should be possible to accept a new mode before it is shown / It should be possible to reject a change in mode / The change should be continuous rather than in steps.</td>
</tr>
<tr>
<td>• Others suggest that showing attention is not needed at all.</td>
</tr>
<tr>
<td>• The information system could show intention if the driver wants this (By a menu or similar).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 C. Show reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The parameters behind the logics could be shown / If the algorithm is complex it should not be shown (1), This type of info is better before and after driving / Don’t believe in briefing.</td>
</tr>
<tr>
<td>• Some suggest that the reasoning could be shown if the driver wants to (e.g. settings).</td>
</tr>
<tr>
<td>• Reasoning should not be shown at all due to information overload.</td>
</tr>
<tr>
<td>• &quot;A really good team player does not need to show intention or reasoning&quot;.</td>
</tr>
<tr>
<td>• &quot;How do you learn to become a team player if no one shows intention or reasoning&quot;.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 D. Understand reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Driver behavior (e.g. input from: Radars, cameras, accelerator, brake, steering, time, GPS, map data).</td>
</tr>
<tr>
<td>• The system needs training to understand the driver (Statistics could be developed for e.g. Most likely path, Time, etc.)</td>
</tr>
<tr>
<td>• Some conclusions could be drawn from how the driver response to information e.g. if the driver discards information many times it may not be wanted.</td>
</tr>
<tr>
<td>• In early stages in product development it can be investigated to what extent a function is requested or not in a certain situation. If there is a low consensus for a function in a situation it should maybe not be automated. (1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 E. Share representation of the problem state,</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fear too much dialogue.</td>
</tr>
</tbody>
</table>
| • Many suggest a dialogue with the agent that shows how the different goals affect each other: The driver could prioritize different goals / Show how the different goals affect each other: e.g. 100% safety gives 10 % sportiness / The impact on different goals are shown: E.g. ACC distance too close => impact on safety / By analyzing driver behavior ("You seem to have this
Feedback: Some kind of feedback from the agent about how driver performs according to goals could be shown.

2 F. Directable, Negotiable levels of authority

- Levels of automation: The level of automation should be adjustable / Most should be good from start but possible to fine tune.
- Levels of help: It is suggested that also the level of help can be changed: In two levels much - little / Distribute information differently over time: First, little information to get to know the system and then more info such as tips and tricks and finally when you know the system, less information again.
- By behavior: If you say NO to some information several time it does not suggest this any longer.

2 G. Negotiable

- The algorithm should be shown for how the agent is reasoning (E.g. how the different goals depend on each other.
- React on input: If the driver inputs travel time to E.g. Stockholm to 4 h. The agent tells the driver that this affects safety, green driving etc....
- This is not a good idea.
- It should be a part of the planning.

2 H. Being observable,

2 I-J. Being gentle, Not overloading, Not clumsy,

- HMI design: Minimalistic / Very integrated functionality / Should not call for attention / Gradually rather than discrete changing information / Reduce number of times information is shown / Settings of how much information: Little - Much.
- Give feed forward information to prepare the driver.
- Don't believe in pre and post trip info.
- Give the correct information at right time.

2 K. What is it doing

- Show which mode it is in and what it is doing (e.g. thinking). The reason for this may be to show that it is consistent.
- HMI Design: Change information without calling for attention, be subtle, like the body language.

2 L. Negotiate

- It should be possible to change level of automation during driving but also change mode manually.
- Some said that it should not be done while driving.
- It could be somewhat adaptive. E.g. Change ACC time gap depending on driving style without ACC.
- It should be possible to reject a change of mode as a way to negotiate.

2 M. Show its limits of performance,

- Show Performance limits: Show signal strength from sensors with a graph bar / Inform discrete levels, Show active or in-active / Inform when passing the limits / Show trend.
- This is not important since this is not directly driving related.
- Show this information may be bad from a competition point of view.
- The system should have limits but it should be possible to override.
- Separate view to see the limits of performance.

2 O. Explain why action,

- Not important.
- This is mainly for urgent warnings.
- Location of this information: Could be located at the same place as intention / It could if people are interested also be shown as briefing or a log afterwards.

2 P. Feedback,

- A time line that shows what has happened.
- Post accident for urgent warnings.
2 Q. Change behavior after negotiation

- The system could change behavior in three different ways: By looking at the response of the information / Post trip evaluation / After some time a question could be shown: The learning period is ended. Do you still want this or that information?

2 R. Give humans feedback.

- Give feedback to the driver depending on goals the agents agreed about.
- Feedback should be: With a positive spirit, moderate and sophisticated.
- Feedback as a coach or a game.

3. Biggest challenge

- To keep the communication on the correct level.
- To match the mental models of the drivers.
- To create robust solution acceptable and enjoyed by most.
- To understand drivers intention.

4 Discussion

4.1 General

It was obvious that the idea of making the automation in a car become a team player was new for the experts. However, they found it challenging, interesting, and agreed on that the idea that making the automation become a team player could reduce some of the problems with automation. They also came up with several ideas of how to improve today's systems - not only about automating information flow but also about their own area of responsibility within the car, such as navigation, active safety and other support systems.

The answers were divergent and showed proof that the idea of making automation a team player is immature, at least among the experts within the car industry (and specifically, at Volvo Cars.)

4.2 Specific comments on the questions

The experts defined a "team player" as someone who achieves an improved result by working together rather than individually and has a holistic view. Team work is built on knowledge of the others and their own performance limits and trust in that each player is doing their best.

The team players find a pleasure in working together.

When discussing how to share a common goal it seems that two extremes are represented: the driver decides all by himself what the goal is by setting a mode (goal) for the trip, or the other extreme where the designer or car dealer decides what is important. In the continuum between some of the experts stated that: "It is not team
work if the driver is the only one in charge", or that the car looks at the driver behavior to adjust the goal.

The most commonly mentioned way of showing intention is to show the next presentation mode that the car plans to enter. It should be presented in a way so that the change does not call for attention. Some suggested that it should be possible to choose if they wanted to see intention or not in a menu. Some also discussed how to reject changes but this might be more correctly located under "Directable" (See table 1). It could also here be stated that the answers are disparate.

Some of the experts don't want to show reasoning at all, mainly because they couldn't find a way to solve this without risk of overload and/or because they couldn't understand why it was important. Others found it more important and suggested a separate view for reasoning showing the algorithms behind the logic in a pedagogic way.

Perhaps the most interesting ideas were made under question 2 C. Some of the experts stated that what the researchers described were not "team players", rather, they were "not yet team players". One expert claimed that "a really good team player does not need to show intention or reasoning" or "A real team player knows what I want". This was commented by another expert that said "But, how do you learn to become a team player if no one shows intention or reasoning"? This is probably the key to the whole issue about making the automation in a car become a team player. In a car, while driving, the visual demands are high and it is therefore not recommended to show too much information. On the other hand, if the system doesn't show intention, reasoning or is directable etc., it is likely to get automation induced errors.

As in the previous point where the agent showed the driver how it is reasoning, the driver should show how s/he is reasoning. As in the other points the answers were rather differentiated. Perhaps a good compromise would be to first use user clinics etc to get a good picture about how people think and then fine tune dynamically by looking at behavior and build a database with historical data to be used to predict driver behavior.

When discussing how to share representation of the problem state some of the experts fear too much dialogue. On the other hand some came up with ideas about how to solve the issue. The main idea was to show how the different goals affect each other (e.g. a view shows that if the driver prioritises sportiness this will affect fuel consumption or safety). It could also be integrated within the different systems (e.g. if you choose this route the sportiness or safety will be two out of ten.

When discussing directability and negotiable levels of authority the experts suggested that it should be possible to choose level of automation and level of help. This may be done in a menu or by adapting to how people respond to information (e.g. if the driver says NO to some information several times the system does not propose this information any longer).
Being gentle, not overloading and not clumsy was discussed mainly in general terms. To summarize, it was mainly about being minimalistic, moderate and careful in the HMI design. However, it was also suggested that feed-forward information could help the driver to reduce workload in critical situations.

The main idea of showing what the system is doing was to change the information without demanding attention. The driver should see the changes only if s/he looks. This could be done by changing information more gradually rather than all at once.

As in several other points the extremes are represented among the answers when discussing if and how to show limits of performance. Some want to show signal strength from sensors and others don't want the information at all. However, also as in other points, it was suggested that showing signal strength could be shown in a separate view possible to look at on request.

It was agreed that an explanation of why an action occurred is mainly important for urgent warnings where intention or reasoning is impossible to show due to time constraints.

One interesting suggestion was to give feedback to the driver depending on goals the agents agreed about. The main thought were that feedback should be: With a positive spirit, moderate and sophisticated, and that feedback preferably is designed as a coach or a game.

On the question about the biggest challenges, the top one was: To match the mental models of the drivers, to keep the communication on the correct level, to create robust solutions acceptable and enjoyed by most and to understand driver's intention.

4.3 Conclusion

Applying the team player approach to car automation seems to be difficult. The main problems are that showing intention, limits of performance, negotiation with or direct automation according to the experts, requires visual attention - visual attention that is also important for the driving task. It is worth mentioning that there were very few experts suggesting other modalities than visual in communicating with the agent.

The experts believed that the approach described by the researchers rather described agents before they become team players than being team players. Real team players do not need to show intention, reasoning etc. The main issue is therefore the journey to become team players. This procedure could perhaps be called "Team building". On the other hand, car manufacturers would prefer automation that do not need specific driver training. It is unlikely that considerable progress could be made in car-driving support if one simply relies on learning by doing [14]. From what has been said in the interviews it seems that a compromise with a separate view for goals, intention, reasoning, limits of performance, negotiations etc. is the most suitable solution.
Future research could investigate other modalities of interaction than visual / manual. It would also be interesting to empirically study if a team player approach applied on car design could reduce automation induced errors.

5 References

Davidsson, S., Alm. (2014). Drive and I tell you who you are. Manuscript submitted for publication.
Drive and I’ll tell you who you are

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1) Volvo Cars Corporation
2) Luleå University of Technology
Abstract

The focus on the road user and possible ways to improve safety has led researchers to identify road users who are supposed to cause more accidents than the average road user. Personality trait can be defined as habitual patterns of behaviour, thought and emotion (Kassin, 2003), and some personality traits are well known to be accident prone.

One of the personality traits that predicts accident involvement is sensation seeking. If we knew whether a person is a sensation seeker it would be possible to adapt the way the warning or information message is transferred to the driver (Palmgreen, et al., 1991).

Boyse (1999) found a correlation between driving characteristics (speed and distance keeping) and personality type A and suggested that information about personality may be used to design more effective driving safety interventions and direct them to accident prone drivers.

Zuckerman (1978) investigated the level of sensation seeking depending on age and gender and found that men are more sensation seeking than women and younger persons are more sensation seeking than older ones.

Thus, would it be possible to use driving characteristics such as lane keeping performance, speed choice, distance keeping performance, brake behaviour, to identify and thereafter adapt driver information to the specific personality trait? This study investigates whether and, if so, how well it is possible to predict a Sensation Seeking score (SS score) using driving parameters collected from vehicle sensors and additional information about age and gender.

Driving data from euroFOT study was first correlated with a Sensation Seeking score. A multiple regression analysis was performed and models to predict Sensation Seeking score by means of driving characteristics were developed.

The correlation study revealed several significant correlations, and significant models that predict sensation seeking were developed.

The correlations and the models were weak but promising. Implications for design were suggested.
**Introduction**

Transportation of people and goods on roads creates a safety problem. The World Health Organization (WHO) estimated in a recent report that 1.24 million people are killed in road accidents annually. Given the size of this problem, attempts have been made to reduce or, if possible, eliminate traffic accidents where people are injured or killed. The transportation system can be classified as a complex and dynamic system composed of road users and vehicles of different kinds, moving in an infrastructure with different characteristics. The interaction between these subsystems may lead to both positive and negative outcomes. To improve safety it is of importance to keep a system perspective. One implication of a system perspective is that changes in one subsystem may have an impact on other subsystems, if they are coupled. For instance, changes in vehicles (for instance studded tyres, antilock brakes) may have an impact on how drivers interact with the vehicles etc.

Attempts to reduce or eliminate accidents have traditionally had a focus on safety critical properties of vehicles, roads or the road users. The human factor, or the road user, has often been pointed out as the main cause of incidents and accidents (c.f. Rumar, 1985). For that reason, it is important to gain a better understanding of the human being as a system component and find possibilities to improve safety.

The focus on the road user as a system component and possible ways to improve safety has led researchers to identify road users who are supposed to cause more accidents than the average road user. Tillmann and Hobbs (1949) introduced the concept of “the accident prone driver” and focused on some drivers’ social and psychiatric background, which leads us to the concept of personality trait.

*Personality trait* can be defined as habitual patterns of behaviour, thought and emotion (Kassin, 2003), and some personality traits are well known to be accident prone. For instance, driving anger, sensation seeking, impulsiveness and boredom susceptibility can predict unsafe driving (Dahlen, Ryan, Martin, Ragan & Kuhlmann, 2005).

One of the personality traits that predicts accident involvement is sensation seeking. Sensation seeking is “a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience” (Zuckerman, 1994). Jonah (1997) found that sensation seeking was significantly correlated to deviant driver behaviours such as speeding, drunk driving, racing the car and low seat belt usage. Zuckerman (1994) explained this such that “high sensation seekers” strive for extra stimulation to achieve an optimal level of physiological arousal.

Thiffault and Bergeron (2003) conclude that subjects who admit having fallen asleep at the wheel previously are likely to rank relatively higher on the sensation seeking score (SSS) than others. This is important; scientific estimates show that up to 10-30 per cent of accidents are caused by drivers falling asleep (For instance: Connor, J., Whitlock, G., Norton, R. & Jackson, R., (2001); Horne, J. & Reyner, L. (1995); Maycock, G. (1997); Stuts, J., Wilkins, J. & Vaughn, B., (1999)).

If we knew whether a person is a sensation seeker, it would be possible to adapt the way that a warning or an information message is transferred to the driver (Palmgreen, et al., 1991). For instance, messages targeted to high sensation seekers have been shown to be efficient. Studies show that persons with a high demand for sensations tend to accept or even need stronger messages to attract and maintain their attention (Donohew, Palmgreen & Duncan, 1980). Another attribute of messages tailored to reach
sensation seekers seems to be that they should be surprising (Banerjee et al., 2011). In addition, it seems possible to replace a risky behaviour with a non-risky one but still giving an equally stimulating task (Roberti, 2004). Davidsson and Alm (2013) suggest that an interesting, challenging and non-distracting quiz can substitute a more hazardous behaviour such as speeding. Thus it seems beneficial to identify and make adaptations to personality traits.

Still, there are very few, if any, examples about how to design a system that supports accident prone drivers. One reason may be that it is difficult to distinguish between different personalities without personality tests and that the common acceptance of the use of personality tests to screen drivers is low. Asking customers to fill in questionnaires or forms in the “purchase of a car” situation or screening for personalities when training, applying for a driving licence or looking for appropriate insurance seems impossible.

However, there may be a feasible short cut. Boyse (1999) found a correlation between driving characteristics (speed and distance keeping) and personality type A and suggested that information about personality may be used to design more effective driving safety interventions and direct them to accident prone drivers.

When searching for parameters that may predict personality, it would also be possible to search elsewhere than in car sensor data as long as other sources are available and useful. For instance, age and gender have an effect on sensation seeking, and this information may be collected during the purchase of a vehicle. Zuckerman (1978) investigated the level of sensation seeking depending on age and gender and found that men are more sensation seeking than women and younger persons are more sensation seeking than older ones.

Thus, would it be possible to by means of driving characteristics such as lane keeping performance, speed choice, distance keeping performance, brake behaviour, identify and then design and adapt driver information to a specific personality trait?

**Hypothesis**

The hypothesis in this study is that it is possible to predict a sensation seeking score from driving parameters collected from vehicle sensors and additional information about age and gender.

**Method**

**Participants**

The material for the study was collected in the European Large-Scale Field Operational Tests on In-Vehicle Systems (euroFOT). Data from 136 participants (55 women and 81 men) with an average age of 46.7 years (SD=9.0) and a range from 18 to 62 years were included in the study.

**Apparatus and procedure**

The data consisted of the Volvo Cars part of the euroFOT project (Bärgman, et al., 2011). In this project 100 cars were equipped with a data acquisition system and driven by regular drivers for one year. Over 25,000 hours of naturalistic driving data were collected during the study. Three types of data were gathered: GPS signals, CAN data and video recordings. The GPS gave the geoposition of the vehicles in
NMEA format, which was consequently merged with a map database to obtain additional information about the vehicles’ position at every point in time. Over 300 signals describing the state of the vehicle were obtained from the CAN bus, all sampled at 10 Hz. The video data were not used in this project.

The conditions of interest in this study were limited to driving on rural roads. The data were filtered using the GPS data with respect to legal speed limit, number of lanes and whether or not the vehicle was in an urban area. A rural road was defined as a road with one lane of travel outside of urban areas and as a road with one lane of travel and a speed limit above 80 km/h within urban areas.

Once episodes of driving on rural roads had been identified, they were divided into 15-second chunks in accordance with Dozza (2012). The variables 3-21 listed in Table 2 were calculated for each chunk. This yielded a database with one entry per chunk with these variables, as well as a numerical driver ID and the distance travelled during that chunk.

The variables calculated can be divided into two categories. First, there are the discrete events that occur during driving that are enumerated by integers. These include, but are not limited to, the number of triggers of a certain warning system or number of lane changes. These are only meaningful with respect to the number of kilometres travelled. The total number of such events was therefore summed per driver and divided by the number of kilometres travelled by that driver.

The second set of variables is the means, maximum, minimum and/or standard deviations of different continuous valued signals from the CAN bus per chunk of driving data. Once the database was complete, the mean and standard deviation of these continuous variables were computed per driver, giving the values used for analysis.

A thorough technical description of how data were collected can be found in Deliverable D3.3 Data management in euroFOT (2011).

Matlab was used to analyse the data. Correlations were studied; this was followed by a multiple regression analysis using SPSS 15.

Variables

**Dependant variable "SS score"**

A modified questionnaire based on the Zuckerman Sensation Seeking Scale (Zuckerman, 1994) was used (see Table 1). The answers ranged between “do not agree at all” to “agree very well” in four discrete steps. The questions were re-arranged after the study such that the more sensation seeking the statement was, the more positive was the total sensation score. The lowest level of sensation seeking was given 1 point and the highest 4. No weighing of the questions was done. There were a total of 20 questions, which gave a highest possible score of 80 points and a lowest of 20 points.
Table 1. The sensation seeking questions

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>I can understand that it might be interesting to marry someone from another country</td>
</tr>
<tr>
<td>b</td>
<td>When it is very cold in the water I’d rather not swim even if it’s a hot day</td>
</tr>
<tr>
<td>c</td>
<td>If I have to stand in a long queue, I generally have patience</td>
</tr>
<tr>
<td>d</td>
<td>When I listen to music, I want to listen at a high volume</td>
</tr>
<tr>
<td>e</td>
<td>When I am travelling, I think it is best to plan as little as possible and take things as they come</td>
</tr>
<tr>
<td>f</td>
<td>I avoid watching movies that I’ve heard are scary or very exciting</td>
</tr>
<tr>
<td>g</td>
<td>I think it’s fun and exciting to perform or speak before a group</td>
</tr>
<tr>
<td>h</td>
<td>If I’m at a theme park, I take rollercoasters or other fast rides</td>
</tr>
<tr>
<td>i</td>
<td>I would like to travel to places that are different and far away</td>
</tr>
<tr>
<td>j</td>
<td>I would never play with money, even if I could afford to</td>
</tr>
<tr>
<td>k</td>
<td>I would have liked to be one of the first explorers in an unknown country</td>
</tr>
<tr>
<td>l</td>
<td>I like movies with lots of explosions and car crashes</td>
</tr>
<tr>
<td>m</td>
<td>I do not like very strong and spicy food</td>
</tr>
<tr>
<td>n</td>
<td>I usually work better under pressure</td>
</tr>
<tr>
<td>o</td>
<td>I often want to listen radio or watch television while I do other things, such as reading or cleaning</td>
</tr>
<tr>
<td>p</td>
<td>I would be interesting to see a car accident happen</td>
</tr>
<tr>
<td>q</td>
<td>I order only things I know when I’m in a restaurant</td>
</tr>
<tr>
<td>r</td>
<td>I like the feeling of standing at the edge of a high place and looking down</td>
</tr>
<tr>
<td>s</td>
<td>If there was an opportunity to visit another planet or moon for free, I would be among the first to report themselves</td>
</tr>
<tr>
<td>t</td>
<td>I can understand that it must be exciting to be in a battle</td>
</tr>
</tbody>
</table>

Table 2. Independent variables were used. Numbers 1 and 2 were collected from an initial questionnaire in the euroFOT study.

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Age</td>
<td>The participant’s age</td>
</tr>
<tr>
<td>2 Gender</td>
<td>The participant’s gender</td>
</tr>
<tr>
<td>3 StdLatAcc</td>
<td>The standard deviation of lateral acceleration</td>
</tr>
<tr>
<td>4 VarLatAcc</td>
<td>Variability in lateral acceleration</td>
</tr>
<tr>
<td>5 StdLongAcc</td>
<td>The standard deviation of the longitudinal acceleration</td>
</tr>
<tr>
<td>6 VarLongAcc</td>
<td>Variability (total change ) in longitudinal acceleration</td>
</tr>
<tr>
<td>7 Speed</td>
<td>Average speed over the segment in m/s</td>
</tr>
<tr>
<td>8 StdSpeed</td>
<td>Standard deviation of velocity in m/s</td>
</tr>
<tr>
<td>9 ACCactive</td>
<td>Boolean indicating whether adaptive cruise control (ACC) is active in the segment</td>
</tr>
<tr>
<td>10 MinDistAhead</td>
<td>Minimum distance to the preceding vehicle in the segment in meters</td>
</tr>
<tr>
<td>11 MeanDistAhead</td>
<td>The mean value of the distance to the preceding vehicle in the segment in meters</td>
</tr>
<tr>
<td>12 MaxRelSp</td>
<td>Maximum velocity relative to the preceding vehicle in km/h</td>
</tr>
<tr>
<td>13 MeanRelSp</td>
<td>The average of the velocity relative to the preceding vehicle in km/h</td>
</tr>
<tr>
<td>14 MeanLP</td>
<td>The average of the distance to the left road marking</td>
</tr>
<tr>
<td>15 SDLP</td>
<td>Standard deviation of the lane position in meters</td>
</tr>
<tr>
<td>16 LaneWidth</td>
<td>Mean of file width in meters</td>
</tr>
<tr>
<td>17 MinTTC</td>
<td>Minimum Time To Collision (TTC) during the segment, measured in seconds</td>
</tr>
<tr>
<td>18 MeanTTC</td>
<td>Mean of TTC in the segment in seconds</td>
</tr>
<tr>
<td>19 MaxTHW</td>
<td>Highest Time Headway (THW) in the segment in seconds</td>
</tr>
<tr>
<td>20 MinTHW</td>
<td>Minimum THW in the segment in seconds</td>
</tr>
<tr>
<td>21 MeanTHW</td>
<td>Mean of THW in the segment in seconds</td>
</tr>
</tbody>
</table>
Results

Correlations

Age and gender were used to investigate whether it is possible to predict an SS score by looking at driving parameter correlations between the SS score and various driving parameters. The parameters in Table 3 (a-c) correlate significantly with the SS score.

*Table 3(a-c). Significant correlations (up to the .1 level) between the SSS and driving parameters. *Not significant at the 5% level.*

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Pearson Corr.</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.33</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>MinDistAhead</td>
<td>-0.24</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.21</td>
<td>.06*</td>
</tr>
<tr>
<td>Km</td>
<td>-0.20</td>
<td>.07*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Pearson Corr.</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.44</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Speed</td>
<td>3</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MeanTHW</td>
<td>-0.24</td>
<td>.06*</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.23</td>
<td>.08*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Pearson Corr.</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.32</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MinDistAhead</td>
<td>-0.20</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MeanDistAhead</td>
<td>-0.20</td>
<td>.05*</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.27</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.24</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Pearson Corr.</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.32</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MinDistAhead</td>
<td>-0.20</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MeanDistAhead</td>
<td>-0.20</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.18</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-0.27</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>MaxRelSpeed</td>
<td>.15</td>
<td>.07*</td>
</tr>
<tr>
<td>MeanRelSpeed</td>
<td>.15</td>
<td>.08*</td>
</tr>
</tbody>
</table>

Stepwise linear multiple regression analysis

A stepwise linear multiple regression analysis was used to quantify how well driving parameters can predict an SS score (criteria: probability of F to enter <= .150, probability of F to remove >= .300).

Sensation seeking

Table 6. Three significant models using driving parameters were found.

<table>
<thead>
<tr>
<th>Models found to predict SS score</th>
<th>Men</th>
<th>Women</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²Adj, p</td>
<td>Predictors</td>
<td>R²Adj, p</td>
<td>Predictors</td>
</tr>
<tr>
<td>.191, &lt;.001</td>
<td>(Constant), Age, MinDistAh, VarLatAcc</td>
<td>.292, &lt;.001</td>
<td>(Constant), Age, MeanLP, Speed</td>
</tr>
</tbody>
</table>

In summary, if other data than from the vehicle (such as gender and age) are available, it would be possible to explain 21.1% of the variance for men and 29.2% of the variance for women in the results of the sensation seeking score. For all persons, 15.8% of the variance is explained.

The models were found to be statistically significant (for men, women and all persons): Fmen(3)= 7.284, p< .001, Fwomen(3)= 8.407, p< .001 and F(all)(2)=13.702, p<.01. Coefficients are shown in Tables 7, 8 and 9.
Table 7. Coefficients for calculation of the sensation seeking score for men.

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>64.633</td>
<td>8.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.277</td>
<td>0.074</td>
<td>-0.385</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>MinDistAhead</td>
<td>-0.283</td>
<td>0.093</td>
<td>-0.309</td>
<td>p&lt;.01</td>
</tr>
<tr>
<td>VarLatAcc</td>
<td>-0.190</td>
<td>0.089</td>
<td>-0.208</td>
<td>p&lt;.05</td>
</tr>
</tbody>
</table>

Table 8. Coefficients for calculation of the sensation seeking score for women

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>75.562</td>
<td>16.358</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.329</td>
<td>0.087</td>
<td>-0.438</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>MeanLP</td>
<td>19.083</td>
<td>8.174</td>
<td>0.269</td>
<td>p&lt;.05</td>
</tr>
<tr>
<td>Speed</td>
<td>0.280</td>
<td>0.121</td>
<td>0.268</td>
<td>p&lt;.05</td>
</tr>
</tbody>
</table>

Table 9. Coefficients for calculation of Sensation seeking score for all

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>75.562</td>
<td>16.358</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.241</td>
<td>0.060</td>
<td>-0.314</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>MinTHW</td>
<td>-3.479</td>
<td>1.064</td>
<td>0.258</td>
<td>p&lt;.01</td>
</tr>
</tbody>
</table>

Discussion

It seems possible to predict the level of sensation seeking from car driving data, gender and age. However, correlations between data and the SSS are generally low and the models only explain a minor part of the variance in the SS score. More effort is needed to find models that are truly useful and utilizable. The major part of the variance is explained by gender and age, which was already described by Zuckerman in 1978.

One possible way to improve this work might be to find other parameters that were not available in the current study and that indicate sensation seeking, for instance belt usage, speed in relation to legal speed, high volume on the stereo and glance behaviour. Glance behaviour seems to be of particular interest since it has been found that sensation seekers look away from the road for longer periods (Pradhan, Bingham, Simons-Morton, Ouimet & Shope, 2014).

Design implications?

This study indicates that information adapted to the driver’s personality trait is possible. There are at least two reasons that this is desirable: first, that blocking and banning to reduce poor behaviour seems unworkable and, second, that it would be more efficient to design for also the extremes within a personality trait than for common people solely.

Today, legislation, disclaimers, blocking and banning are common countermeasures to avoid poor driver behaviour, such as speeding and exposing oneself to distracting activities. Unfortunately, these seem to be inefficient among sensation seekers, and there are even examples of them being counterproductive. For instance, the number of accidents increased by between 1-9% when a texting ban was introduced (Holbrock, 2010) in some states in the USA. One reason is that those who anyway text hold the phone at
a lower level in order to avoid fines, which increases the eye time off road and in turn increases the risk for accidents.

Furthermore, the efficiency of legislation on cell phone restrictions for teenagers in North Carolina had no long-term effect on the behaviour of teenage drivers (Goodwin, O’Brien & Foss, 2012), and the worst is that it appears that many teenage drivers shift from talking on the phone to texting, which has been found to be far more dangerous than talking (Olson, 2009).

One explanation for why banning and blocking etc. may be inefficient is that sensation seekers are willing to take physical, social, legal and financial risks for the sake of a sensational experience (Zuckerman, 1994). Another explanation may be that a state of psychological reactive may be stimulated when people perceive that their freedom is limited, which may be reflected in drivers’ disobedience in terms of behaviour and attitude (Brehm, 1966).

It is natural that system designers design for the large majority of the population. They want to reach as many as possible and often make priorities according to a normal distribution, where the majority of efforts are invested around the average. However, this approach may exclude typically accident prone drivers.

A more efficient approach may be to identify and then design and adapt technology to, for instance, sensation seekers. A few examples of what can be done, given that it is known that a driver is a high sensation seeker, are as described below:

- Studies show that persons that are high sensation seekers tolerate or even need stronger messages to attract and maintain their attention (Donohew, Palmgreen and Duncan, 1980) and that messages should contain a component of surprise (Banerjee, Greene and Yanovitzky 2011).
- Replace risky behaviour with non-risky behaviour that is an equally stimulating task (Roberti, 2004). For instance, Davidsson (2013) suggests that an interesting, challenging and non-visually distracting quiz can substitute more hazardous behaviour, such as speeding.
- Achieve a behavioural change among different personalities by tailoring safety campaigns such as are described in Ulleberg (2002).
- Adapt the driving training to also include higher motives and norms (Hatakka, Keskinen, Gregersen & Glad, 1999), especially those with a high SSS.
- Thiffault and Bergeron (2003) suggest that more monotonous driving journeys should preferably not be carried out by high sensation seekers (or to extroverts) who score high on sensation seeking. A navigation system may perhaps be able to suggest different routes depending on personality.

**Limitations**
The material from the euroFOT was originally not collected for the purpose of finding correlations or creating regression analyses from sensation seekers and car data. Some data were therefore not available. Belt usage, entertainment volume and glance behaviour may perhaps have been helpful.

**Methodological considerations**
When analysing the existence of a mass significance problem on the 5%-ile significance level, ~1-2 significant parameters are to be expected among 30 variables. In the whole population, the numbers of
significant correlations were six, among men three and among women only one. The results should therefore be interpreted with care.

Furthermore, the models included predictors that were not significantly correlated to the SSS (VarLatAcc: R=-.100, p=.37; MeanLP: R=.211, p=.123) in the single correlation, Table 4. One probable cause is that a “suppressor effect” appeared and that the variables do therefore not correlate with the score by themselves.

Data from the warning system of the vehicle were also used. Unfortunately, these data were shown to be corrupt and were therefore excluded from the statistical analysis.

Further research
Sensation seekers are among those who are accident prone drivers. However, there are several other personality traits that can also be targeted for adaptability because of an increased risk in different circumstances. Examples are people who are susceptible to, boredom (Thackray, 1975; Eysenck, Pearson, Easting, & Allsopp, 1985), persons with type A behaviour (Nabi et al., 2004), extroverts (Fine, 1963; Eysenck, Pearson, Easting, & Allsopp, 1985; Thiffault & Bergeron, 2003; Gange, Geen & Harkins, 1979; Taylor & McFatter, 2003; Smith & Maben, 1993), introverts (Casagrande, 2002; Stenberg et al., 1990; Wilt & Revelle, 2007) and people with different locus of control (Rotter, 1966; Lajunen and Summala, 1995; Roberts & Geller, 1995; Rudin-Brown & Noy, 2002). All have their particular problems in different situations.

One obvious question for further research is of course whether drivers want the car to identify, calculate and store their level of personality traits. It is possible that the benefits described above may not be above the integrity issue.

References


Holbrook, E. (2010) Increase in Accidents Since Ban on Texting. *Risk Management*, 57, 10; ProQuest Central, p44


Rumar, K. (1985). The role of perceptual and cognitive filters in observed behavior. In *Human behavior and traffic safety* (pp. 151-170). Springer US.


Countermeasure drowsiness by design - using common behaviour

Staffan Davidsson
Luleå University of Technology, Sweden and Volvo Cars Corporation

Abstract. This study takes a starting point in what drivers do to avoid drowsiness while driving instead of starting with what researchers know is efficient (Take a short nap). It is concluded that research is missing when it comes to how efficient common behavior countermeasures are and that there is a mismatch between research and how people actually behave. A three stage approach which includes identification, information and countermeasure is suggested. Furthermore are a few ideas of what car manufacturers can do to support human behavior presented.

Keywords: Tiredness, drowsiness, countermeasures, system design

1. Introduction

1.1. Background

The lowest figures in accident statistics about how many accidents are caused by drivers falling asleep begins at 1-3 percent [1-3]. Other scientific estimates show a lot higher figures, 10-30 per cent [4-8]. Regardless of which figure is true, a lot of people get killed every year due to drowsiness.

The research focus has so far been on reason for and the detection of sleepiness and there are just a few research articles that addresses the countermeasures [9,10]. However, some of the car manufacturers have designed warning system that warns the driver if it is indicated that the driver is drowsy. One example is Volvo Cars that introduced a system called Driver Alert. This system shows a coffee cup and ask/suggest the driver "Time for a brake" if it is indicated that the driver is in-alert.

This may be a correct countermeasure. Almost all experts agree on that the only truly effective strategy drowsy drivers can take to prevent a crash is to immediately stop driving and get some sleep.

According to for instance [9] is "Letting someone else drive for 1-2 hours while you sleep in the passenger seat before driving again" and "Pulling off road to take a 30-45 minute nap" the most certain behaviours that will result in increased alertness in a drowsy/sleepy driver.

If this is not possible, drivers should be encouraged to stop and drink some caffeine [11].

The first question that is addressed in this paper is if people act accordingly to this research?

The second question the author would like to address is the suspicion that people take other actions than what researchers recommend. They simply continue to drive.

One reason for not stopping and take a nap may be that the drivers either, do not feel drowsy or do not recognize or admit their feelings of drowsiness [8].

There may also be other countermeasures or strategies that drivers typically employ – rolling down the car windows, turning up the radio, stopping to stretch – However, these are largely unsupported by the scientific literature. The motivation to reach the goal may be more important than to drive safely. Drivers think. "I can handle this." This bias is confirmed by occasions where they have been drowsy but still managed to arrive safely at their destinations [8].

So, what do we do? People get killed when they fall asleep, researchers know what to do to but drivers continue to drive. The third question in this paper is therefore if it is possible to learn from common, anecdotal or not, behaviour and develop highly ac-
cepted or even enjoyable vehicle systems that are used and can keep the driver alert.

For instance, a hopeful and recent study [13] demonstrated that a motivating cognitive stimulation while driving has the potential to suppress fatigue symptoms caused by underload driving conditions. Interactive cognitive tasks (ICTs) can play a role in eliminating hazardous situations caused by underload. Another study [14] confirms that this may be a mean to avoid performance decrement but associate it with a cost.

Furthermore, a study [16] that used pre-loading tasks to move mental demand from high demand situations to situations where there is low demand in order to avoid decrement of performance, indicate promising effect. The efficiency of the means will not be investigated further in this study but opens up for further research.

2. Method

2.1. Tools

A small pilot study was performed to get as many action options as possible to choose from. 14 different activities were identified. An Internet survey was created in the tool "Surveymesh" (www.surveymesh.se). The survey contained background question about gender, age, years holding a driving license and how many kilometers they drove per year.

The subjects were then given the opportunity to choose one or several of the 14 actions that they use to do if they felt tired. Then they were asked if there activity worked, how often they used the activity, on which road type they easiest get tired, after how long time and at which time they get tired. The exact wording can be seen in the result part. The participant got the possibility to give multiple choices when necessary.

The subjects were recruited from different social media such as Facebook. The different options presented were not randomly varied due to limitations of the "Surveymesh" tool. After looking into the survey figures a brainstorm session took place, giving suggestions on how to use the common behavior in system design. These suggestions are not included in the result part but some examples are shown in the discussion.

2.2. Subjects

The survey was completed by 44 (59.5 per cent) men and 33 (40.5 per cent) women. The average age among the participants was M: 44.5 years, SD: 9.4. The number of years with a driving license was in average M: 25.6 years, SD: 9.5. 52.7 per cent drove between 10000 to 20000 km, 24.3 per cent drove less than 10000 km, 17.6 per cent drove between 20000 and 30000 km and only 5.4 per cent drove more than 30000 km per year. The survey was in Swedish why all of the subjects know Swedish.

3. Result

The result of the study is presented in the tables below.

Table 1. What do you do when you drive and start to feel tired?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change seating position</td>
<td>45</td>
<td>16.1</td>
</tr>
<tr>
<td>Pull over and get some fresh air</td>
<td>37</td>
<td>13.3</td>
</tr>
<tr>
<td>Increase the fan and reduce temperature</td>
<td>36</td>
<td>12.9</td>
</tr>
<tr>
<td>Play loud music</td>
<td>30</td>
<td>10.8</td>
</tr>
<tr>
<td>Open the side window</td>
<td>27</td>
<td>9.7</td>
</tr>
<tr>
<td>Talk to passengers</td>
<td>25</td>
<td>9.0</td>
</tr>
<tr>
<td>Drink Coffee</td>
<td>25</td>
<td>9.0</td>
</tr>
<tr>
<td>Sing</td>
<td>19</td>
<td>6.8</td>
</tr>
<tr>
<td>Listen to people talking or discussing on the radio</td>
<td>17</td>
<td>6.1</td>
</tr>
<tr>
<td>Activity</td>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------</td>
<td>-----</td>
</tr>
<tr>
<td>Pull over and sleep</td>
<td>9</td>
<td>3.2</td>
</tr>
<tr>
<td>Talk in the phone</td>
<td>5</td>
<td>1.8</td>
</tr>
<tr>
<td>Play “car games” e.g. count red cars or count numbers on registration plate...</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td>Look at the nature</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td>Write and read SMS (Text messages)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2.

Do you experience that your activity work?

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1= Not at all</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>6= Yes, a lot</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>4.6</td>
</tr>
</tbody>
</table>

Table 3.

How often do you use these activities?

<table>
<thead>
<tr>
<th>How often</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A few times every year</td>
<td>38</td>
<td>52.1</td>
</tr>
<tr>
<td>A few times every month</td>
<td>19</td>
<td>26.0</td>
</tr>
<tr>
<td>Very seldom (&lt; once a year)</td>
<td>14</td>
<td>19.2</td>
</tr>
<tr>
<td>Daily</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>A few times every week</td>
<td>1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 4.

On which road types do you easiest get tired?

<table>
<thead>
<tr>
<th>Road type</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor way</td>
<td>55</td>
<td>67.9</td>
</tr>
<tr>
<td>Highway (Rural road)</td>
<td>25</td>
<td>30.9</td>
</tr>
<tr>
<td>City road</td>
<td>1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 5.

After how long drive do you use to get tired?

<table>
<thead>
<tr>
<th>After how long drive do you use to get tired?</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-4 hours</td>
<td>26</td>
<td>32.5</td>
</tr>
<tr>
<td>1-2 hours</td>
<td>23</td>
<td>28.8</td>
</tr>
<tr>
<td>30 minutes - 1 hour</td>
<td>14</td>
<td>17.5</td>
</tr>
</tbody>
</table>
4. Conclusion and Discussion

4.1. Mismatch

Regardless of the knowledge among researchers do not very many "ordinary" drivers pull over and sleep when they get tired. Only 3.2 per cent of the participants use this activity when tired. Instead seems physical changes be the most common activity. The physical changes "Change seating position", "Pull over and get some fresh air", "Increase the fan and reduce the temperature" and "Open the side window" represented half of the answers.

Experts believe that these activities work moderately. It is therefore clear mismatches between what drivers in this survey do and what is accepted as efficient in the research community.

Interestingly is the number of activities that can be classified as cognitive not very high. For instance, was "Listen to people talking or discussing on the radio " and "Talk in the phone" only used by 6.1 and 1.8 percent respectively, of the participants. It should be mentioned that talking in mobile phone is not prohibited in Sweden.

On the other hand may "Talk to passengers" be included in this group of activities and this represents 9 per cent of the activities. Verbal conversation also seems to be one way to reduce drowsiness even if the effect only last for a limited period of time [12].

Luckily, does not anyone in the survey use texting (SMS) as a mean to avoid falling asleep. It has been shown that text messages increases risk for accident twenty three times when texting while driving [17].

It seems that most of the subjects are fairly satisfied with the result of their strategy to cope with tiredness. One interesting question that has to be raised is if the participants in this study are wrong or if their activities actually work?

Is their behavior only based on misleading confirmation bias or are the current methodology insensitive for these types of activities? If the methodology is only sensitive to what really works, drivers are wrong and we have to continue as today, working out information and warning campaigns. If the methodology is in-sensitive and the activities actually work is it perhaps possible to develop well accepted systems or services that help drivers to stay alert.

Today some car manufacturers provide warnings or information about that the driver may be tired. However, the car does not provide any help to reduce tiredness. In a future system can other validated functions hopefully also get the driver other countermeasures to fight tiredness.

4.2. Three stages to support driver

It can be suggested that to avoid tiredness while driving three stages are needed:

1. Identify tiredness: improve sensitivity in the measurement of tiredness by using available map data, time and driving hours. Most of the tiredness occurred on the motorway, after 1 hour and in the early morning and the late afternoon. "Driving hours" and at "which time" it is most likely to get tired has also been confirmed in for instance [14].
2. Inform or warn about tiredness. Suggest countermeasures.
3. Provide means based on activities drivers perform today to avoid tiredness. The car suggest countermeasures such as:
   - Automatic seat adjustment/movement.
   - Lower temperature and increase fan automatically when there are indications of poor alertness.
   - Suggest a coffee brake.
   - To sing seems both fairly efficient according to the experts in [9] and used in 48 percent of the answer. Can a Karaoke activity without the text row be efficient?
   - Not very many play "car games" while driving and the experts seem to not find it very efficient. However, the research [13] shows different result and if it is correctly designed to not distract it may be useful.

4.3. Limitations

Recruitment through the social media is extremely convenient. However, the control over the respondents answering the questionnaire is of course limited. In this study the main idea was to identify different activities and give a rough figure what drivers do when they get tired. It was not important if "Pull over and sleep" was more common than for instance "Playing car games".

An effect of the poor control of the participants was that the average age was higher than expected. This may have a large impact on the result since younger drivers are over-represented in the drowsiness crash statistics [15]. The small pilot study identified a lot of different activities and give a rough figure what drivers do when they get tired. It was not important if "Pull over and sleep" was more common than for instance "Playing car games".

An effect of the poor control of the participants was that the average age was higher than expected. This may have a large impact on the result since younger drivers are over-represented in the drowsiness crash statistics [15].

The small pilot study identified a lot of different activities. However, some may have been forgotten and therefore not quantified. One such activity was "Increase speed" which afterwards, in the free text was found to be an activity used by some drivers. Future studies can quantify how common this activity is to improve alertness and if it is useful.

4.4. Further research

As mentioned earlier is this study only a start. More participants with a more complete age profile and different cultural background must be involved in future studies.

It would also be interesting to go further in the analysis. For example, for those first 5 actions, that most people apply, would they work better than the other actions? Another question could be how drivers combine these activities and which effect that might give.

From a methodological perspective may a more naturalistic study sort out if these common activities work or not? Several other research questions can easily be identified now when the common behavior is given a chance.

References

Driving Simulator Investigation Human Factors: The Journal of the Human Factors and Ergonomics Society


Towards a model to interpret driver behaviour in terms of mismatch between real world complexity and invested effort

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Abstract. Driving behaviour has been less documented than driver workload. The possibilities to define a framework that could be part of a driving behaviour model were investigated. The results present a framework that defines twelve scenarios in which drivers have misinterpreted a driving situation. The descriptions show evidence of increased user experience for some scenarios while other indicates reduced traffic safety. The results suggest that by using the framework-descriptions on how and why mismatches occur, design guidelines for in-vehicle systems can be developed.

Keywords: Workload, user experience, framework, safety, in-vehicle system

1. Introduction

Improved car design in terms of passive and active systems has contributed to substantial improvements in driving safety over the past 50 years. During the same period of time several human information processing models have been developed within the field of human factors and ergonomics. These models describe limitation in terms of human performance \cite{18} during situations of different levels of workload, and have been used to minimize risk of accidents in the process-, the flight-, and the automotive industry.

The Human Computer Interaction (HCI)-industry also make use of human factors and ergonomics knowledge \cite{2}. In contrast to the risk-approach used in the other industries, the HCI-industry has focused on human behaviour, e.g. in terms of usability and user experience (UX) issues \cite{6}. The term UX include a wide variety of meanings, ranging from traditional usability to beauty, hedonic, affective or experiential aspects of technology use \cite{6}. In addition, the methods that include usability and UX are included in the toolbox for designers of consumer products while methods that include workload-models are not \cite{1}.

Car systems have similar requirements, and designers with similar education as those in the consumer product domain. However, in driving, human mental workload and performance is different from human behaviour. Performance reflects a person’s capability in a certain environment, whereas behaviour is that person’s actual actions in the same environment as they are mediated by the person’s goals, needs, and motivation \cite{14}. Models of driver performance have successfully described how many perceptual and motor limits influence driving performance, but models of driver behaviour still await development \cite{13}.

Therefore, the objective of this research was to outline a model of driver behaviour that included definitions familiar to designers of consumer products.
1.1. Driving safety

Drivers most often adapt their behaviour and drive safely [15]. Even if there are individual differences, for example depending on age, drivers know their skill-level and adapt their behaviour to the complexity of the present driving situation. For example, older drivers might reduce there driving during dark hours and complex traffic situations. On the other hand, even if young drivers also adapt their behaviour they may overestimate their level of skill. This overestimation may affect their driving behaviour towards the real complexity in a specific traffic situation [13].

The results from the 100 car study [11] show that when an incident or an accident has occurred there is clear evidence of poor driver behaviour. Reports [11, 12] from the study show a direct relationship between driving behaviour and crash/near-crash involvement in terms of odds ratio (OR). The reports show that various secondary tasks increased OR compared to driving (OR=1). For example: Reaching for a moving object (OR=8.82), Looking at external object (OR=3.70), Applying makeup (OR=3.13) and Dialling a hand-held device (OR=2.79). On the other hand, the results showed that some secondary tasks actually reduced OR. For example: Adjusting the radio (OR=0.55), Talking to a passenger in the adjacent seat (OR=0.50), Talking to a passenger in the rear seat (OR=0.39), and Combing hair (OR=0.37).

Based on these results future advancements in reducing traffic safety risks will depend on enhancing driving performance by improving driver behaviour. To do this there is need to clarify why drivers sometimes engage in tasks that increase risk, and how this behaviour can be reduced.

1.2. Human performance

The Multiple Resource Theory (MRT) present explanations of human’s limited resources in different modalities, and also suggest optimal combination of modalities, codes and responses during the different stages of the information process [18]. MRT can be used to understand multiple-task interference.

Engineering psychology models, such as the MRT, emphasize human’s limited mental capacity and due to the use of technical metaphors, such as "filter" or "computer", they are readily accepted by engineers and thus have influence on system design in the car domain. This can be exemplified by IDIS (Intelligent Driver Information System), a system that delay incoming phone calls and text messages, in order to reduce the potential for driver information overload [3].

The limited capacity models described above, however, have not taken into consideration human’s capability to adapt to different situations. That may explain why less design effort has been put on systems that support adaptive behaviour.

1.3. Driver behaviour

Drivers change their behaviour depending on their goals, needs, and motivation [14]. For example, when a stressor appears, such as an increased risk in a traffic scenario or when drivers select to engage in other tasks than the driving task they take different actions to compensate for the changed demand. For example, drivers can change strategy, add resources or remove stressors [9]. Driver can also choose to do nothing which may affect driving performance negatively. Moreover, drivers can compensate for changed demand by mobilizing effort. The effort mechanism is active in the case of attention demanding information processing, or in the case that the operator’s state differs too much from the required state [8]. According to this theory, central executive mechanisms compare the current cognitive state with a required or target state. Whenever there is a mismatch between these two states, changed effort can actively manipulate the current state towards the target state. By investing mental effort the detrimental influences of stressors can be successfully counteracted. A similar way to compensate for changed demand is to adjust distance to factors such as: time to collision, smooth and comfortable travel and rule following [17]. This mechanism results in a comfortable state called "comfort zone".

The same way of reasoning can be used for In Vehicle Information Systems (IVIS). If an IVIS feels difficult to use drivers either increase safety distance or avoid using the IVIS-function. For example, a driver can turn the volume down on the radio when stressed, turn the telephone off in complex driving situations, and wait to input a destination until the car is stationary. Hence, strong links can be found between the driving task, UX, and driving safety.

This reasoning is also supported by several simulator studies that have shown that drivers change their behaviour in situations with different levels of complexity. For example, a study on driver attention found that drivers abandoned the Peripheral Detection Task (PDT) when the driving task got to difficult. This behaviour obviously resulted in worse PDT per-
formance but at the same time the driving performance measures were improved [19]. A similar change of driving behaviour was found in a study that investigated effects of different touch screen positions [5]. The simulator study tested four positions (near high, near low, far high, far low), and the results showed that drivers sacrificed the speed on the in-vehicle task to maintain safe driving performance in a similar manner as they would do on the road [5].

All the above mentioned theories and studies show that drivers adjust their behaviour in various situations to maintain their comfortable and safe zone. To be able to understand why they sometimes do not adapt their behaviour, this paper is meant to contribute to a first step towards a model to interpret driver behaviour. In this first step we have limited our work to define mismatch-scenarios. We have therefore left out other factors that influence driving behaviour such as: strategies, skill and motivation [9, 16], see figure 1.

1.4. Purpose

The purpose of this paper was to define mismatch-scenarios that could occur while driving, and to arrange these scenarios in a framework that emphasized driver behaviour.

2. Method

A literature study and a workshop were performed to gather information to the framework which was supposed to interpret driving situations that contain combinations of driving related and non-driving related tasks. The suggested framework was based on previous research on workload [4, 10] and divided into three constructs that may be aligned or separated:

1. **Real world complexity (RC)** describes the combined complexity of a single and/or multiple tasks that a driver engages in during driving in a specific situation. Thus, the real world complexity represents the same level despite driver's capacity.

2. **Subjective complexity (SC)** describes the perceived complexity or the expectancy towards a specific situation. The subjective level can differ depending on personality, self confidence etc.

3. **Invested effort (IE)** describes the amount of effort that a driver chooses to invest in relation to the perceived complexity in a specific situation.

Moreover, it was defined that if one or more constructs failed to match with any other level in the framework, a mismatch had occurred. For example, if a driver would adapt perfectly to the real world complexity of a specific situation all three constructs in the framework would be aligned, i.e. drivers matched their invested effort according to the subjective complexity level and the real world complexity.

After defining the terms framework and the mismatch they were discussed in a one-day workshop with six human factors professionals. The professionals were: two professors with more than 20 years experience in several human factors domains (including the automotive), two representatives from a car manufacturer with more than 10 years experience in designing in-vehicle systems within the automotive domain, and two PhD candidates that performed research in interaction design issues related to the automotive domain. The literature study and the workshop results were summarised in a report which has been the basis for this paper.

3. Results

Based on the definition above, thirteen mismatch-scenarios were identified, see table 1. Scenario 0 represents normal driving while scenarios 1 through 12 were mismatch-scenarios. Among the mismatch-scenarios 1-6, one construct diverted from the other two. Scenarios number 7-12, on the other hand, included mismatch between two constructs, see table 1 and figure 2.
Mismatch scenarios. When real world complexity (RC), subjective complexity (SC), and invested effort is in the same box no mismatch is present. When the constructs (RC, SC and IE) are in different boxes there is a mismatch-scenario. Scenario 0 represents normal driving while scenarios 1 through 12 are mismatch-scenarios.

<table>
<thead>
<tr>
<th>Scenario no. / Levels</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level x-1</td>
<td>IE</td>
<td>RC, SC</td>
<td>IE</td>
<td>RC, IE</td>
<td>SC</td>
<td>RC</td>
<td>SC</td>
<td>IE</td>
<td>IE</td>
<td>SC</td>
<td>RC</td>
<td>SC</td>
<td>SC</td>
</tr>
<tr>
<td>Level x-2</td>
<td>IE</td>
<td>SC</td>
<td>IE</td>
<td>RC</td>
<td>SC</td>
<td>RC</td>
<td>SC</td>
<td>RC</td>
<td>SC</td>
<td>SC</td>
<td>RC</td>
<td>SC</td>
<td>RC</td>
</tr>
</tbody>
</table>

In scenarios 1, 6, 7, 8 and 9 the invested effort was lower than the real world complexity (RC>IE). These types of mismatch-scenarios indicate increased probability of risky driving behaviour and worse UX.

In scenarios 3, 5, 9, 10 and 12 the subjective complexity was higher than the real world complexity (SC>RC). These mismatch-scenarios indicate increased risk of worse UX.

In scenarios 2, 5, 10 and 12 the invested effort was higher than needed according to the real world complexity (IE>RC). These mismatch-scenarios indicate increased risk of fatigue.

In scenarios 4, 6, 7, 8 and 11 the real world complexity was higher than the subjective complexity (RC>SC). These types of mismatch-scenarios indicate increased probability of risky driving behaviour.

In scenarios 2, 4, 8, 11 and 12 the invested effort was higher than the subjective complexity (IE>SC). These types of mismatch-scenarios indicate increased probability of better driving behaviour and better UX.

In scenarios 1, 3, 7, 9 and 10 the subjective complexity was higher than the invested effort (SC>IE). These types of mismatch-scenarios indicate increased probability of risky driving behaviour and worse UX.

To further understand and interpret the scenarios, all three constructs in the framework (RC, SC and IE) have to be analysed simultaneously. This result was not fully exploited in this paper, however, a few examples where simultaneous analysis has been made were developed, see table 2 and figure 2.

Table 2
Examples on detailed descriptions of mismatch-scenarios.

<table>
<thead>
<tr>
<th>Scenario no.</th>
<th>How</th>
<th>Why</th>
<th>Design implications (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Regulation of effort match with perceived need and task complexity</td>
<td>Most common state. Normal/Good driving behaviour. No missing schema.</td>
<td>Not needed</td>
</tr>
<tr>
<td>4</td>
<td>Invested effort and real world complexity is matched but task is perceived easier than it is</td>
<td>Good design, simplistic, good UX.</td>
<td>No countermeasures needed. Good UX</td>
</tr>
<tr>
<td>6</td>
<td>Don’t see Don’t understand</td>
<td>Hidden hazard Missing knowledge Missing Schema Gulf between evaluation and execution</td>
<td>Feed forward Educate Design to reduce gulf. Difficult task should be perceived as difficult</td>
</tr>
<tr>
<td>7</td>
<td>Subjective complexity estimated less than the real world complexity. Put less effort into the task than perceived.</td>
<td>Personality. Similar to 0, i.e. the normal state for this personality. Wrong &quot;Main driving Schema&quot; Hidden hazard Missing knowledge Missing Schema Gulf between evaluation and execution</td>
<td>Coaching, encouragement, social media Fed forward Educate Design to reduce gulf. Difficult task should be perceived as difficult</td>
</tr>
<tr>
<td>11</td>
<td>Task complexity is perceived low. Still put a lot of effort into the task.</td>
<td>Personality, careful, waste effort may cause fatigue Good design, simplistic, good UX.</td>
<td>Not needed for UX. Coaching needed for increased safety.</td>
</tr>
</tbody>
</table>
4. Discussion

The purpose of this paper was to define mismatch-scenarios that could occur while driving, and to arrange these scenarios in a framework that emphasized driver behaviour.

In difference to other models that focus on users limited resources, i.e. situations of overload [18], this framework describe mismatch-scenarios that affect driving safety and UX. The framework is based on the assumption that drivers adapt their behaviour and drive safely in a majority of all driving situations [15], and that they indeed have available resources to solve a majority of all driving situations. However, when drivers for different reasons misinterpret the actual situation the framework suggest that there is a mismatch between one or two constructs.

4.1. The framework

In scenarios where the invested effort generally is lower than the real world complexity (RC>IE: scenario 1, 6, 7, 8 and 9), design implications can be how to design the road environment and in-vehicle systems to be perceived as difficult. In scenarios where the subjective complexity is higher than the real world complexity (SC>RC: scenario 3, 5, 9, 10 and 12) the driver instead experience risk. It may also, in the long run, be negative for traffic safety if drivers waste more effort than needed, as in scenario 2, 5, 10 and 12 (IE>RC). A challenge for these scenarios includes how to bring the driver back in the comfort zone to increase UX. This can be done, for example, by designing the road environment and in-vehicle systems to be perceived as ease.

Moreover, the descriptions that are presented in table 2 and figure 2 show a more detailed analysis. For example in Scenario 0, drivers manage to regulate effort according to the real world. This is the most common driving behaviour and does not include any design implications. In Scenario 4, on the other hand, drivers perceive the task as is easier than it is, even though the invested effort is aligned with the real world complexity. This "mismatch" is wanted and a result of good design that support UX. In Scenario 6 drivers invest as much effort as they think is appropriate to meet the real world complexity. However, a misinterpretation leads to less invested effort than needed and e.g. increased traffic risk. This risk can be reduced by feed forward information or by education. In Scenario 7 drivers perceive the task as less difficult than it is. However, they invest less effort than needed, for example due to complacency. Examples on design implications can be coaching, social media etc. In Scenario 11 drivers perceive the task easier than it is but still invest more effort than needed to meet the real world complexity. This can be good for UX, however too much waste effort may cause fatigue.

![Figure 2. Examples of possible mismatches. Mismatch-scenario number 0 represents normal driving, number 4 and 6 represents single mismatch-scenarios while number 7 and 11 represents double mismatch-scenarios.](image-url)
4.2. Effects on traffic safety and user experience

Even if drivers obviously can change their behaviour towards their goals, needs, and motivation [14], and towards the real world complexity [5, 19], it is clear that drivers are involved in scenarios that include mismatch between real world complexity and invested effort. Many of these mismatch-scenarios clearly occur due to driver's behaviour. The 100-car study show that risk for incidents and accidents increase when drivers are reaching for moving objects, looking at external object, applying makeup, and dialling hand-held devices [11, 12]. Many of these, particularly those with the highest odds ratio (1. Reaching for a moving object, 2. Looking at external object, and 3. Applying makeup) are tasks in which the drivers engage in a voluntary manner, and thus are more difficult to reduce with design measures. On the other hand, the same study shows that some tasks actually reduce accident risk (1. Adjusting the radio, 2. Talking to a passenger in the adjacent seat, 3. Talking to a passenger in the rear seat, and 4. Combing hair). These results show that drivers can increase traffic safety, by, e.g. make use of simple in-vehicle-tasks while driving. Hence, an in-vehicle-system that is sensitive for changes in driver behaviour, e.g. IDIS [3], can encourage drivers to talk to passengers or use the radio to increase traffic safety.

Moreover, it has been found that drivers’ subjective estimates of distraction with the actual distraction effects (the distracting effects of a hand-held or hands free cell phone conversation) are not well-calibrated [7]. However, training to recognize or attend more closely to driving activities may help drivers’ determine when their performance is below the real world complexity [7].

4.3. Conclusions

In most cases, the perceived complexity in driving situations is aligned with the real world complexity and the invested effort. This paper suggests a framework that analyse driving situations from a perspective of mismatch between real world complexity, subjective complexity and invested effort. The results show twelve mismatch-scenarios that can be used to analyse safety and user experience. By using the framework descriptions on how and why mismatches occur can be developed, and implications for design can be defined.

In conclusion, the results reported here offer an opportunity to develop a safety and user experience model with descriptions and implications for interaction design. The framework can also be further expanded into design guidelines for in-vehicle systems.

4.4. Further work

Models of driver performance have successfully described how many perceptual and motor limits influence driving performance, but models of driver behaviour still await development [13]. Further research should be added to the framework developed in this paper. Examples on research questions are:

- Which mismatch-scenarios are relevant for safety and UX?
- Are there difference between single and double mismatch-scenarios in terms of safety and UX?
- Do skill and motivation affect mismatch?
- How do the different factors that influence driving behaviour relate to each other?
- How can the defined mismatch-scenarios be confirmed and measured, during driving, during tests in simulator and by subjective methods?
- Will this framework be easier to use for designers of in-vehicle systems compared to previous workload-models?

References


The concept of ‘pre-loading’ is introduced as a potential means of countering mental underload by giving the operator an additional, task-related activity during times of low workload to maintain their attention. A driving simulator study was conducted to evaluate this concept with a view to designing adaptive systems around a pre-loading activity. 27 participants drove in a simulator under low and normal workload conditions, with and without pre-loading. Although none of the objective performance metrics showed significant differences, pre-loading did significantly increase subjective mental workload. The results are interpreted with respect to implications for underload theories as well as experimental design recommendations for future research in this field.

Introduction

It has long been accepted in ergonomics research on mental workload that overload and underload are equally detrimental to performance (see e.g., Young and Stanton, 2002). Under Malleable Attentional Resources Theory (MART; Young and Stanton, 2002), underload is explained by a shrinkage of attentional capacity in conditions of excessively low mental workload. Consequently, any sudden increase in workload will be beyond the capacity limit of the operator – even if such a level of demand would ordinarily have been within their ability to cope.

One practical implication of MART as an explanation for underload is that attentional capacity may be optimised if the operator engages in some additional task activity (cf. Young and Stanton, 2002). Thus, where mental workload is
otherwise low, the operator undertaking an additional task could artificially stimulate their attentional resources, avoid underload and improve performance (cf. Young and Stanton, 2007). Indeed, Gershon et al. (2009) showed that an interactive cognitive task can suppress fatigue symptoms caused by underload in driving. But such a strategy is associated with several concerns when it comes to safety-critical performance domains such as driving, largely because the additional task could then lead to the opposite problem — overload.

For instance, MART could be used to argue that drivers facing a low workload driving task (e.g., a monotonous motorway journey) could conceivably make a mobile phone call and actually improve their driving performance. Indeed, there is even evidence in favour of such a view (Liu, 2003), and it is consistent with suggestions that drivers have up to 50% spare capacity during routine driving (Hughes and Cole, 1986). Nevertheless, this particular tactic does not sit well with road safety advice, or the significant ergonomics and human factors evidence base on the increased crash risk associated with phoning and driving (see e.g., Collet et al., 2010). Problems will inevitably arise when primary (driving) task workload increases, causing conflict and overload. Rather, the authors prefer the notion that drivers engage in a task-related activity, so that if workload does increase, their attention is at least directed towards the driving task.

Alternatively, there has been much research into adaptive systems to maintain optimal mental workload over time (e.g., Parasuraman and Hancock, 2001). These systems detect the operator’s current level of workload, and then adjust the level of automated support to suit — taking over when demand peaks, handing control back during troughs in workload. A prototype adaptive system evaluated by Piechulla et al. (2003) used complex task-based modelling to detect mental overload, and used the output to route incoming phone calls to voicemail during overload periods. The results showed some promise, and a similar system is now marketed on some Volvo vehicles. So far, though, we have not seen any similar efforts to manage the problem of mental underload.

In the current paper, we propose and evaluate a conceptual adaptive system which takes the two approaches described above in combination. That is, it provides the driver with additional, task-related activity during periods of low workload, which is specifically designed as preparatory activity for a later, anticipated peak in demand. In a sense, this is a kind of temporal adaptivity, which we have termed ‘pre-loading’ in this paper. For example, one of the ironies with current satellite navigation devices is that they provide the driver with additional assistance at precisely the moment when driving task workload has increased — i.e., at a junction. One implementation of the pre-loading concept might then be a satellite navigation system which provides information about a forthcoming junction much further in advance than typical devices do, at a time when workload is lower. In the present experiment, we use a hazard identification task in a driving simulator to pre-load drivers’ attention on the driving task in order to see whether this concept would
improve performance in underload scenarios – and conversely whether it would degrade performance in overload scenarios.

**Method**

**Design**

Based on MART (Young and Stanton, 2002), the key hypothesis for this study was that an additional, task-related activity during underload conditions would improve performance on the primary task. Since MART predicts an inverted-U relationship between workload and performance, a related hypothesis is that the same task-related activity would degrade performance under normal workload conditions, since the additional task now overloads the driver.

A 2x2 mixed design was used for the present study. The first, between-subjects factor was primary (driving) task workload – low or normal – manipulated by changing steering demands in the driving simulator, based on the assumption that steering is a key determinant of driver mental workload (Young and Stanton, 2004). In the low workload condition, steering demands were minimised by designing a straight road scenario in the simulator, whereas the normal workload scenario presented a series of bends throughout the run.

The second independent variable, a within-subjects factor, was presence or absence of the pre-loading task. This task consisted of a series of hazard perception questions, such as “what was the sign you just passed”, or “what was the colour of the car at the last junction”, and was based on advanced driving tests (such as that advocated by the UK’s Institute of Advanced Motorists). The pre-loading task was intended to increase drivers’ attention to the driving task.

In addition, at the mid-point of the run, a critical event occurred which required drivers to react in order to avoid a collision. The event consisted of an overtaking car pulling into the subject vehicle’s lane ahead, and then braking harshly to a standstill. The critical event occurred in all conditions. Regardless of how the critical event had been dealt with, the run resumed but in all conditions, the driving scenario reverted to the ‘normal’ workload level, and there was no pre-loading task. Another critical event then occurred at the end of the run, the purpose of which was to determine how well attention recovers from overload/underload.

In all conditions, the main driving task was to maintain a consistent 60mph throughout the run. As such, there was no conflicting traffic in the scenario (other than the critical event), although other overtaking vehicles (to act as foils for the critical event) and some opposing traffic was present. Furthermore, with respect to the pre-loading task, the surrounding road environment (scenery, roadside furniture etc.) was kept consistent across all conditions, with the exception of variations in the specific details addressed by the hazard perception questions (e.g., colour of car,
road sign) in order to minimise learning effects. Order of presentation of conditions was counterbalanced across participants. Finally, a peripheral detection task (PDT) was embedded into the scenario for an objective measure of attentional capacity.

Dependent variables included primary task measures of driving performance (whether or not they crashed in response to the critical event), number of missed responses and reaction time to the PDT, and subjective mental workload using the NASA Task Load Index (TLX; Hart and Staveland, 1988).

Thus, with respect to the design and hypotheses, our predictions regarding driving performance are summarised in table 1 below.

<table>
<thead>
<tr>
<th>Low workload</th>
<th>Normal workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor (underload)</td>
<td>Good (optimum workload)</td>
</tr>
<tr>
<td>Good (compensated underload)</td>
<td>Poor (overload)</td>
</tr>
</tbody>
</table>

Participants
In total, 27 participants took part in the study, 14 of whom were male. The average age of the sample was 36.0 (SD = 12.7), and they had held a full UK driving licence for an average of 13.0 years. 14 participants were randomly allocated to the low workload condition; in this subsample there were eight males, the average age was 34.1 (SD = 12.6), and the average number of years holding a driving licence was 9.54 (SD = 8.75). In the high workload condition, then, there were 13 participants (six male), average age 38.5 (SD = 13.1) and average years with a licence of 17.0 (SD = 15.5). Participants were recruited from the Brunel University driver participant pool.

Apparatus
The Brunel University Driving Simulator (BUDS) was used for this study. BUDS is a fixed-base, fully interactive immersive simulator based on a 2006 Jaguar S-Type full vehicle body. The driving simulator software is provided by STISim (Systems Technology Inc, Hawthorne, CA; Build 2.08.04), which has state-of-the-art graphics hardware enabling a real-time, fully-textured, anti-aliased, 3-D graphical scene of the projected virtual world. The images are projected via three Toshiba TDP-T95 digital projectors onto three 2.4 m x 2.0 m (viewable area) screens at a resolution of 1280 x 1084 pixels, thus giving the forward facing scene plus the left and right peripheral scenes. In total from the driver’s seat the projection covers a 150˚ horizontal and 45˚ vertical field of view. Simulated images of the dashboard instrumentation as well as rear view and side mirrors are projected onto the viewing screens. The simulator is controlled by a Logitech multimedia driving unit (G25 Racing Wheel) consisting of steering wheel, gear lever and pedal block (including
clutch pedal), fitted in the car as a UK-standard right-hand drive vehicle. The Logitech driving unit allows for simulation of manual or automatic transmission, with manual being used in the present study. The frame rate and data capture rate throughout the study were fixed at 30 Hz.

Procedure
Participants were introduced to the simulator and given a five-minute practice run. Instructions were then given for the main experimental trials, including the directive to drive at a constant 60mph, as well as information on the pre-loading task where relevant. The scenarios were of a fixed distance, and so when driving at the instructed speed, each trial took approximately 12 minutes to complete.

During the scenario, the PDT appeared in the top left and right corners of the screen, and consisted of red diamond symbols. At 24 predefined points throughout the scenario, one of these symbols would change to a red triangle. The driver’s task was to respond as soon by pressing a button on either side of the steering wheel corresponding to which symbol had changed. If no response was made within three seconds, a ‘miss’ was recorded and the symbol reverted to its default. PDT events were randomised for each driving cycle and feedback condition.

During the pre-loading conditions, seven predefined questions were delivered at specific times in the scenario corresponding to driving-related hazards. The frequency of these questions was approximately one question every one to two minutes. As specified in the Design, these questions ended with the first critical event, and so were not presented during the second half of the trial.

At the end of each trial, participants completed the NASA-TLX. Two sets of scales were given, and participants were asked to complete the first relating to the first half of the scenario (up to and including the first critical event), with the second relating to the second half of the scenario.

Results

Primary task performance
Table 2 shows the frequency of crashes in each condition, for the first and second critical events. A chi-square test did not find any differences in these data ($\chi^2(3, N=27) = 2.14, p = 0.544$).
Table 2: Frequency of critical event crashes in each condition

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<th>Without pre-loading</th>
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<td></td>
<td>First</td>
<td>Second</td>
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<tr>
<td>Low workload</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Normal workload</td>
<td>9</td>
<td>4</td>
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Peripheral detection task

Table 3 shows mean reaction times to the PDT events in each condition, separated by the first and second half of the trial (i.e., before and after the first critical event). A 2x2x2 ANOVA, comparing the within-subjects factors of pre-loading task and pre- or post-critical event, against the between-subjects factor of workload condition, did not reveal any significant main effects or interactions.

Table 3: Mean reaction times (s) to PDT in each condition

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<tr>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>Low workload</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td>Normal workload</td>
<td>1.07</td>
<td>1.12</td>
</tr>
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</table>

Table 4 presents the total frequency of missed responses to the PDT. A chi-square test did not reveal a significant result ($\chi^2(3, N = 27) = 1.92, p = 0.590$).

Table 4: Frequency of missed responses to the PDT in each condition

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<tr>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>Low workload</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Normal workload</td>
<td>9</td>
<td>17</td>
</tr>
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</table>

Subjective workload

Table 5 shows mean overall workload data from the NASA-TLX. A 2x2x2 ANOVA (as per the PDT reaction times) revealed a significant main effect for the pre-loading task ($F(1,24) = 18.4, p < 0.001$), and a significant interaction between the pre-loading task and the phase of the trial (pre- or post-critical event) ($F(1,24) = 8.14, p < 0.01$). Furthermore, results approaching significance were returned for the pre- vs. post-critical event phase of the trial ($F(1,24) = 3.07, p < 0.1$) and the interaction between phase and workload condition ($F(1,24) = 3.20, p < 0.1$).
Table 5: Mean TLX overall workload scores in each condition

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<tbody>
<tr>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>Low workload</td>
<td>34.8</td>
<td>38.1</td>
</tr>
<tr>
<td>Normal workload</td>
<td>38.5</td>
<td>36.7</td>
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</table>

As can be clearly seen from these data, the presence of the pre-loading task resulted in increased scores on the TLX. Post-hoc exploration with paired t-tests revealed that the source of the interaction between pre-loading and phase of drive was a significant decrease in overall workload between pre- and post-critical events only in the conditions with the pre-loading task ($t(26) = 2.66, p < 0.05$); in contrast, this difference was non-significant for conditions without the pre-loading task.

Regarding the trends for phase of drive, descriptive data show a marginal drop in overall workload across all conditions between the pre- and post-critical event phases of the drive. Again, the trend towards an interaction was due to a significant reduction from pre- to post-critical event only in the normal workload condition ($t(12) = 2.41, p < 0.05$); this difference was non-significant in the low workload condition.

Discussion

Clearly, the pre-loading task had no effects on any of the objective performance measures in this study, but it did have an impact on subjective mental workload as measured by the TLX. Perceived workload was higher when the pre-loading task was present, and there was a pronounced drop in the second phase of the drive after the pre-loading task had ceased. Contrary to expectations, though, the second phase of the drive (when all conditions reverted to ‘normal’ workload) did not result in an increase in perceived workload for the low workload condition; rather, the opposite occurred, in that there was a slight drop over time in the normal workload condition.

There are several possible explanations for these results. Firstly, as far as subjective workload is concerned, it is an accepted limitation of such methods that retrospective rating of a task is prone to inaccuracy – especially in the present context where we were trying to obtain two sets of ratings for the same drive. Nevertheless, participants were clearly sensitive to the pre-loading task and felt it increased their workload.

That there was no effect on either objective metrics of attention or performance, though, suggests that the pre-loading task does not have the anticipated effects in terms of compensating for underload. It is possible that the low workload condition in the present experiment was not low enough to induce underload – despite the fact...
that we had pared the driving task back to a minimal amount. The implication of this might be that theories of underload, such as MART (Young and Stanton, 2002), are in fact automation-specific. That is, the underload effect is actually a qualitatively different phenomenon from very low workload, and may then not be so distinct from automation-related explanations such as out-of-the-loop performance (e.g., Endsley and Kiris, 1995).

Alternatively, we may look to the experimental design. We have mentioned the possibility that the low workload task was not low enough; it is also possible that the pre-loading task was not enough of a load. Both of these possibilities could account for the absence of differences at either end of the workload curve (i.e., no underload with low workload, no overload with high workload). More work needs to be done on making the experimental tasks more distinct before concluding that a pre-loading task is ineffective. Furthermore, although we focused on the main outcome measures in the present paper, there are also more performance data to analyse from the simulator, which may yet reveal differences between the conditions.

In conclusion, then, although the results did not prove the hypotheses, the pre-loading task was clearly noticeable to participants and it may have an effect – desirable or undesirable – under different conditions. More research is necessary on the current dataset and with similar experimental designs before abandoning the approach, since this is the first study of such a concept. Either way, the results of such research could have implications for theories of underload as well as applied relevance in the design of automated systems.

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ABSTRACT
To investigate the impact of visualizing car uncertainty on drivers’ trust during an automated driving scenario, a simulator study was conducted. A between-group design experiment with 61 Swedish drivers was carried out where a continuous representation of the uncertainty of the car’s ability to autonomously drive was displayed to one of the groups, whereas omitted for the control group. The results show that, on average, the group of drivers who were provided with the uncertainty representation took control of the car faster when needed, while they were, at the same time, the ones who spend more time looking at other things than on the road ahead. Thus, drivers provided with the uncertainty information could, to a higher degree, perform tasks other than driving without compromising with driving safety. The analysis of trust shows that the participants who were provided with the uncertainty information trusted the automated system less than those who did not receive such information, which indicates a more proper trust calibration than in the control group.

Categories and Subject Descriptors
H.1.2 [User/Machine Systems]: Human factors

General Terms
Design, Human Factors, Experimentation

Keywords
Uncertainty visualization, trust, automation, driving, acceptance.

1. INTRODUCTION
Technological advances have led to the development of numerous driver assistance systems such as adaptive cruise control, lane departure warning, collision avoidance, automatic parking and driver drowsiness detection systems. Experiments with fully autonomous cars have also been carried out, which provides us with a glimpse of what the future might hold. The purposes of developing such support systems are to make driving safer, easier, more relaxing and more enjoyable. However, such goals can only be achieved if the driver feels comfortable enough to hand over control to the automation and if a good cooperation between the driver and the automation can be achieved. Studies from other domains, such as the aviation domain, have shown that the anticipated positive effects of automation might be diminished due to human-automation cooperation related problems, such as automation misuse and disuse [1, 2], automation surprises and mode confusion [3, 4], reduced situation awareness [5], complacency as well as over reliance on the automation [6]. To reduce the possible negative effects of automation, while at the same time reinforce the positive ones and promote a safe and appropriate usage of the automation, several researchers have highlighted the importance of informing the human operators of the strengths and limitations of the automated systems used, as well as the continuous state of the automation (see for instance [7-11]). For example, in the study by Stanton and McCaulder [12], it became evident that the drivers had insufficient knowledge of the limitations of the adaptive cruise control system, resulting in collisions due to the drivers’ inappropriate levels of trust in the automated system. This finding is in line with the research reported by Dzindolet et al. [13] and McGuirl and Sarter [7] where it was found that operators who were provided with continuous feedback regarding the performance of the automated aid had more appropriate trust in the aid than operators who were not given such information.

We argue that more research is needed to evaluate the effectiveness of providing feedback on changes in the automated system’s capability during autonomous driving. To the authors’ knowledge, no research has addressed how to convey the limits and performance of automatically driven cars to their drivers as a means to achieve appropriate trust. As such, the objective of this study was to evaluate the effects of visualizing a continuous representation of car uncertainty on the drivers’ trust in the automatic support system used. We hypothesized that such visualization would make the drivers able to more appropriately calibrate their trust in the system while at the same time making them aware of the limitations of the system. We also hypothesized that the uncertainty representation would result in better prepared drivers in take-over situations as well as that the drivers who were presented with the uncertainty information would, to a higher degree, perform other tasks than driving during the test scenario. Finally, we hypothesized that the uncertainty representation would result in drivers being able to look away from the road to a higher degree.

The paper is structured as follows: section 2 provides information regarding advances within the area of uncertainty and system reliability visualization. Section 3 presents the study setup, whereas section 4 reports on the study findings and section 5
presents a brief analysis of the results. Section 6 discusses the results obtained whereas the conclusions and ideas for future work are found in section 7.

2. RELATED WORK

The visualization of uncertainty in the context of automatic driving has been recently studied by Beller et al. [14]. The aim of this study was to evaluate whether communicating when the car was uncertain using a symbol (a face with an uncertain expression) improved the driver-automation interaction. A driving simulator experiment varying the level of uncertainty with 28 participants was conducted. The results show that the presentation of uncertainty information increases the time to collision in cases of automation failure, that situation awareness was improved and that automation with the uncertainty symbol received increased acceptance and higher trust ratings. These positive results regarding the visualization of information related to smart systems in cars seem to coincide with previous studies, i.e., Verbene et al. [15] and Seppelt and Lee [8].

Seppelt and Lee [8] investigated if a visual representation of the adaptive cruise control (ACC) behavior promote appropriate reliance and support effective transitions between manual and ACC control. Twenty-four participants were recruited to drive in two different situations, with different failure types. In traffic conditions, the participants relied more appropriately on ACC when the information about the ACC was present. Moreover, it promoted faster and more consistent breaking responses and show other positive effects in other traffic situations. The authors suggest that providing drivers with continuous information about the state of the automation is a promising alternative to providing warnings.

The work presented by Verbene et al. [15] focuses on investigating if representations of descriptors of three ACCs with different automation levels that either shared their driving goals or not affected trustworthiness and acceptability of those systems. A driving experiment with 57 participants was carried out. The results show that ACCs that took over driving tasks while providing information were more trustworthy and acceptable than ACCs that did not provide information.

Several relevant works regarding the influence of uncertainty visualization on decision-making can be found in other research areas, such as the military domain. For example, Finger and Bisantz [16] studied the use of blended and degraded icons to represent uncertainty regarding the identity of a target contact as hostile or friendly. The first part of the study showed that participants could sort, order and rank five different sets of icons conveying different levels of uncertainty. In the second part of the study, three of the pairs of icons were used in an application in which participants should identify the status of contacts as friendly or hostile. Three conditions were studied: with degraded icons and probabilities, with non-degraded icons and probabilities and with degraded icons only. The results demonstrate that participants using displays with only degraded icons performed better on some measures and as well on other measures, than the other tested conditions. Thus, the use of distorted or degraded images may be a viable alternative to convey situational uncertainty.

Wang et al. [17] examined the effects of presenting the aid reliability on trust and reliance on a combat identification (CID) scenario. Twenty-four participants carried out a simulated CID task, half of whom were told the reliability level. The results show that response bias varied more appropriately with the aid reliability when it was disclosed than when not, and that trust in aid feedback correlated with belief in aid reliability. The authors highlight that to engender appropriate reliance on CID systems, users should be made aware of system reliability.

3. METHOD

3.1 Participants

A total of 61 participants (31 male, 30 female) between 27 and 58 years old (4 between 20–29 years, 21 between 30–39, 21 between 40–49 and 13 between 50–59) with an average age of 41 years took part in the simulator experiment. The participants were selected from a population of 488 Volvo employees, mostly non-technical personnel of whom none is involved in the development of functionality for autonomous driving or the implementation of the driver’s information module (DIM). The only prerequisite for taking part in the study was that the participant had a driver’s license.

Each participant was randomly assigned to a display conditions. A balanced latin square design was used in order to minimize the effects of participants driving early in the morning, directly after lunch and late in the afternoon. This led to 31 participants (16 males and 15 females) driving with the added uncertainty information and 30 participants in the control group.

3.2 Procedure and questionnaire

The participants were first informed of the purpose and setup of the study. Thereafter, all participants were allowed to drive the car simulator in manual mode for about 3–5 minutes so as to get acquainted with the simulator. Directly after the training session, the participants were informed of the prerequisites of the test session: that the car could drive autonomously due to its lane keeping ability, but that the performance of the automatic driving system was coupled to the weather conditions. The participants were also informed that they could at any time take control over the car by steering/breaking/giving gas to the car in accordance with their own assessment of the appropriateness of using the system. The DIM was explained to both of the groups; however, the uncertainty representation (see Figure 1) was presented and explained to only one of the groups (hereafter “with uncertainty information group”). Before the start of the test session, the participants were informed that there were newspaper and sweets at their disposal in the passenger seat if they so pleased. Thereafter, the 9-minute test session started.

After the test session, the participants were asked to fill out a questionnaire about their trust in the system, using a modified version of the trust in automation scale [18]. The participants answered seven questions such as “I am confident in the system” and “I can trust in the system” using a seven point Likert scale ranging from 1 (fully disagree) to 7 (fully agree).
Figure 1: Graphical representation of the ability of the car to drive autonomously, ranging from 7 (very high ability) to 1 (no ability). The red marking indicates the threshold for when the performance of the automated driving system no longer can be guaranteed.

3.3 Simulator
The experiments were carried out at the Human Machine Interaction (HMI) laboratory at Volvo Car Corporation, Gothenburg, Sweden. The laboratory contains several integrated systems: a driving simulator and a fully functioning cockpit (see Figures 2 and 3).

Figure 2: Driving simulator, Volvo Car Corporation HMI lab.

Figure 3: Overview of HMI lab

The participants drove the car simulator through a snowed and fogged two lane country side road. Due to the weather conditions, the degree of visibility varied from 0% to 100%. When the visibility was worst, the car simulator could no longer follow the road marks, the car uncertainty representation showed the lowest level and the automation could no longer maneuver the car. At this moment, the driver had to act accordingly by taking control of the car (either breaking or steering). The driving scenario lasted approximately 9 minutes.

3.4 Collected data
Logs from each simulator session were recorded. The quantitative data thus collected corresponds to values from steering angle, break, acceleration, look away time and weather conditions. Cameras and an eye tracking system were used to record all the sessions.

In addition to the quantitative data, qualitative data was collected through observing the participants. The data collected included to which extent the driver had his/her hands on the steering wheel, if the participant stayed on the road after take-over and if the participant read the newspapers or ate the sweets provided.

4. RESULTS
Of the 61 recorded simulator sessions, two were omitted due to participants not taking control of the car before the simulation ended (one from each group). The remaining 59 sessions were analyzed according to our three hypotheses.

Regarding time to take-over (TTO), the group provided with the uncertainty representation needed 1.9 seconds to take control of the car on average while the control group needed 3.2 seconds.

The individual results are shown in Figure 4 below.

Figure 4 – Individual results of time to take over

The differences between the two groups are summarized in Figure 5 below.
The results were submitted to a one-way ANOVA analysis. The analysis showed that, with a 95% certainty, there is a statistically significant difference between the two groups (p-value = 0.02).

Regarding looking away from the road, the group provided with the uncertainty representation, on average spent 18% of the driving time looking at other things but the road, while the control group was looking at other things 12% of the time on average. The individual results are shown in Figure 6 below.

The differences between the two groups are summarized in Figure 7 below.

A one-way ANOVA analysis showed that, with a 95% certainty there is a statistically significant difference between the two groups (p-value = 0.03).

In addition to the proportion of the total time spent on looking at other things than the road ahead, the number of times drivers looked away for more than 2 seconds were counted, since this is regarded as the limit for how long a driver can look away while maintaining awareness of the situation ahead [19]. The group provided with the uncertainty representation looked away for more than 2 seconds 8.0 times on average, while the control group looked away 5.0 times on average (see Figure 8 below).
A one-way ANOVA analysis (α = 0.05) showed that there is no statistically significant difference between the two groups with respect to looking away from the road ahead for longer periods of time (p-value = 0.12).

Trust was assessed using the scale for trust in automated systems developed by Jian et al. [18]. Participants of both groups answered the questions after the driving exercise, using a seven point Likert scale ranging from 1 (fully disagree) to 7 (fully agree). The questions are listed in the appendix. The results are shown in figures 9-10. The mean of the scores was used as an overall trust score (as presented by Beggiato and Krems [10]). The average trust value for the control group was 5.30, while the group with uncertainty representation shows an average trustworthiness of 4.89.

Reliability was measured using Cronbach’s alpha values. The values obtained, 0.87 (with uncertainty representation) and 0.85 (control group) show a good internal consistency (0.8 ≤ α < 0.9).

5. ANALYSIS

The results confirm the hypothesis that presenting the uncertainty of the autonomous systems results in better prepared drivers in take-over situations. The difference in look away times between the two groups manifested itself in that of the 33 drivers that stayed on the road after take-over, 20 (61%) were drivers provided with the uncertainty information.

The results also confirm the hypothesis that the uncertainty representation would result in drivers being able to look away from the road to a higher degree. Although looking away more in terms of total time compared to the control group, the drivers who were presented with the uncertainty information did not look away for longer periods of time more often.
Regarding the hypothesis that the drivers who were presented with the uncertainty information would, to a higher degree, perform other tasks than driving during the test scenario, the collected qualitative data confirms that to some degree. Of the 15/21 drivers who read the newspapers/ate of the sweets, 9/11 (60%/52%) were from the test group. More important, of the drivers that read the papers and drove off the road at take-over, only 20% were from the test group. Of the 28 drivers that, to a lesser or greater extent, kept their hand on the steering wheel during the test, 12 (43%) were drivers provided with the uncertainty information. More important, of the drivers that kept their hands on the wheel and drove off the road at take-over, only 20% were from the test group.

To summarize, the results show that drivers provided with the uncertainty information performed better in take-over situations and they were also more comfortable with performing other tasks while driving, as compared to drivers without this information.

6. DISCUSSION

Results from the study show that the drivers who were informed of the car uncertainty were better prepared in take-over situations. Also, these drivers had better calibrated their trust in the automatic driving system, whereas the control group reported on higher trust ratings despite the needed manual take-over in the scenario used in the training sessions. These findings are in line with the work presented by McGurk and Sarter [7] where the participants who were informed of the system confidence were better able to more appropriately calibrate their trust in the decision aid.

Even though the drivers with certainty information were better prepared to take control of the car while, on average, spending more time doing other activities, the results show that the trust scores for this group were worse than the group without aid. The findings reported in this paper are in contrast to the ones reported by Beller et al. [14] and Seppelt and Lee [8], that recommend that providing drivers with continuous information about automation is preferable to providing warnings, and that information about automation increase trust and acceptance. A possible explanation for interpreting our results can be found in Dzindolet et al. [13], where the role of trust in automation reliance is studied. Their findings suggest that participants initially considered automated decision aids trustworthy and reliable, but, after observing the automated aid make errors, participants distrusted even reliable aids, unless an explanation was provided regarding why the aid might err. Knowing why the aid might err increased trust in the decision aid and increased automation reliance, even when the trust was unwarranted. Thus, it should be further investigated if the visual representation of the car uncertainty used in our study should be complemented with additional information regarding why the level of uncertainty was high.

Another representation of the car’s ability to autonomously drive could have generated different results than the ones obtained. According to Seppelt and Lee [8], not just any representation of continuous information will enhance driving performance. In the experiment presented in [8], it was concluded that the use of color dilution to represent sensor degradation in a rain condition was not an effective cue. Further, to combine a graphical representation of uncertainty together with a haptic and/or sound etc. could result in better performance regarding time to take over times and longer look away times.

Individual differences in trust in automation and automation reliance should be further explored. Lee and Moray [20, 21] found strong individual differences in automation use – some participants were prone to use manual control, others were prone to use automation. As such, future work should include a further analysis of the results in relation to the participants’ estimated locus of control and driving styles.

Several limitations of the study should be mentioned. The driving scenario and exercise might be considered very simple, but it was designed to analyze the effect of uncertainty information and how the drivers would take over the control of the car when automation could no longer guarantee a safe drive, thus, we tried to minimize other experimental variables that could affect the driving task and affect our analysis on trust and automation reliance. It might be that the simplicity of the scenario made some of the participants in the test group neglect the uncertainty representation and concentrated on the weather conditions instead. Moreover, the uncertainty of the automation could have been associated with additional parameters than the weather, such as other contextual information, e.g. the traffic situation.

Regarding the validity of the study here presented we would like to highlight that during the design of the experiment we ruled out extraneous variables that could affect our study on trust issues and automation making as simple scenarios as possible (e.g. avoiding dense traffic or overtaking situations) guaranteeing, thus, internal validity. An experiment has external validity (generalizability) if the results are not unique to a particular set of circumstances, but generalizable. We are confident that the large number of participants in this study, as well as the selection criteria applied, make the results presented generalizable.

7. CONCLUSIONS

This paper has reported on an empirical study performed together with 61 drivers in a simulator experiment, were the effects of displaying continuous support system uncertainty during an automated driving scenario was evaluated. The results indicate that drivers who were informed of the car uncertainty were better prepared to switch to manual control when required than the control group. Further, the control group showed tendencies of automation bias, resulting in inappropriate calibrations of trust, which is also in line with research presented by [13], where it was concluded that people generally have positive expectations of unfamiliar automated decision aids.

Future work will include additional data collection regarding the participants in the study so as to associate the results with information regarding the drivers’ driving style and their perceived subjective locus of control. Future work will also explore other driver-automation forms of collaboration. As discussed by Inagaki [22], for the human-automation collaboration to progress, the automation might need to implement some control actions when it determines that the human is in a condition where he/she is unable to give directives to the automation, resulting in automated technologies that are able to understand the human’s psychological and physiological conditions, intentions and actions in relation to the situation. In a driving scenario, such cooperation could be based on the automated car’s understanding of the current status of the driver.
(alert, sleeping, texting etc.) and adapt the level of automation and the frequency of warnings accordingly.

The transition of control is also a topic which needs further structuring and investigation [23]. According to Flemisch et al. [11], there are many questions that need to be investigated regarding the proper balance between the driver and the automated systems, especial about the authority of the assistance and automated systems in emergency situations. How to design such driver-automation handovers must also be further explored.

APPENDIX

Listed below are the questions for measuring trust answered after the driving exercise:

- Q1: I understand how the system works – its goals, actions and output
- Q2: I would like to use the system if it was available in my own car
- Q3: I think that the actions of the system will have a positive effect on my own driving
- Q4: I put my faith in the system
- Q5: I think that the system provides safety during driving
- Q6: I think that the system is reliable
- Q7: I can trust the system

REFERENCES


