Adaptive Driver Information

The way forward?

Staffan Davidsson
LICENTIATE THESIS

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The Chameleon could illustrate what adaptivity is. Some varieties of chameleon use their colour-changing ability to blend in with *context*, as an effective form of camouflage.

Colour change is also used as an expression of the *state* or physiological condition of the lizard, and as a social indicator to other chameleons. Some research suggests that social signalling was the primary driving force behind the evolution of colour change, and that camouflage evolved as a secondary concern.

Their ability to rotate their eyes gives them a full 360-degree arc of vision around their body. The eyes can be moved independently of each other which make them superior at *divided attention*.

Context, state and attention are three important issues discussed in this thesis.
Acknowledgements

It has been fun and exciting to write this thesis thanks to a lot of people. My supervisor, Professor Håkan Alm, has for instance not only introduced me to the world of research and his best friend Keppel, but also to Indian food. Thank you also for the too few but very intense and good meetings we have had.

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Thanks also to SAFER that let me spend so much time in their nice facilities and drink of their coffee, which is far better than Volvo Car's.

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Abstract

Driver information is information that a driver needs to fulfil his or her goals of driving. Previously, information supported reliability in order to make the car work safely but, today, other attributes have become equally or more important. Driver information also needs to support safe, efficient, legal, environmentally friendly and enjoyable transportation.

Functional growth is expected due to new technology, new purposes of driving and customers’ desires. One way to meet functional growth and at the same time improve drivers’ situation awareness and optimize workload may be to make driver information adaptive. The information presented, the output factors, could change salience governed by different input factors such as driver state, context, situation etc. However, changing information automatically may cause new types of errors, such as mode error, over-trust, under-trust, vigilance problems or change of locus of control. These types of errors belong to the category automation induced errors.

The aim of this thesis was therefore to investigate whether adaptive driver information has a potential to improve driver performance, support goals of driving, improve situation awareness (SA) and optimize workload. This question was decomposed into four more specific research questions. (1) What are the purposes of future driver information and their relations to different functions? (2) What are the potential benefits and negative effects of adaptive driver information? (3) What information do drivers need and want throughout the driving task? (4) How can the negative aspects of adaptivity be avoided by design?

In paper A, the purposes of driver information were identified and linked together with future driver information components and, as a result, several new functions were identified. The different benefits and negative effects were identified by literature studies. However, the scope was extended to the aviation and power industry, which has greater experience of automation. In paper B, functions were mapped to different contexts. The results can be used as a guideline for future design. The different negative effects of automation were handled in paper C by applying the “team player” approach to car design. The results showed a potential in the “team player” approach, but it was also clear that the visual impact on driving must be solved.

It seems that adaptive driver information has a potential to improve driver performance, support goals of driving, improve situation awareness and optimize workload.

Key words: Driver Information, safety, adaptivity, automation, mental workload
List of appended papers

**Paper A**


**Paper B**


**Paper C**

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1 Introduction

1.1 Background
Let's first take a huge step 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.

Cars not only give positive effects such as the possibility for goods or people to be transported. Cars and their drivers can also cause accidents. For instance, Cugnot's vehicle crashed into a wall in 1771 due to a lack of the most fundamental safety equipment, brakes, and the first car accident was a fact (Hansson, 1990). More recent safety figures are not encouraging. During 2007, 471 persons died in traffic accidents in Sweden only (Swedish Road Administration, 2009).

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, 2009).

Despite the intensive work on more efficient engines, power trains and new fuels there is always a potential in the human part of the system to reduce the carbon footprint, for instance, or to improve safety.

1.2 Driver information
Information is provided to the driver by many different sources: from the road authority via traffic signs, traffic lights, road markings or traffic messages etc.; from the car's different instruments, navigation or warnings systems; and from the
environment by for instance noise and visual flow. In this thesis, driver information is defined as driver information that a car manufacturer could provide to a driver. This means, for example, instruments in the car, but also internet access to the car from home for planning or feedback.

The need for driver information has been the biggest issue and the instrumentation's main task was most likely to show the status of the vehicle in order to avoid breakdowns that could lead to accidents or high costs.

Let's have a quick look at today's instrumentation. The main idea behind the tachometer, for instance, is to show how many revolutions the crank shaft turns in one minute. Some 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 which indicates too high rpm. It is sometimes used to see if the engine is running, which sometimes can be hard to hear. It is used by very few drivers and 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 a speed, which makes the red part useless. Strangely, it is moreover also common to have a tachometer in cars with an automatic gear box.

The coolant temperature gauge can be used during start-up, for instance, to avoid overload of a cold engine. During very warm conditions it could also be used to see if the engine is overheated, however, most of the time, this gauge is not used at all.

It could be argued that the reason for having a speedometer is to show 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 in this thesis it is argued 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, it does not show braking distance and it does not show how fast you have to go to be at the destination in time.

It seems that there is a great potential to improve driver information. A great deal is missing and it could be argued that most of the current instruments exist mainly for historical or traditional reasons.

Today, other issues such as safety, efficiency and environmental friendliness are of the same or even higher dignity. New technology such as GPS, radar sensors, optical sensors, Wi-Fi, 3G and high resolution displays are available, but not very much has been done to change the information in order to support these issues.

1.3 Outline of thesis
The thesis follows a structure starting with a discussion of the previous purposes of driver information. Several explanations for why a change of driver information is
needed are thereafter presented. The section that deals with future driver information is then finalized with the purpose of the thesis and the research questions.

The frame of reference, chapter 3, gives the main issues concerning adaptive driver information. Previous work and some driver models are presented together with sections about the purpose of driver information, situation awareness, workload and automation. There is a discussion after each section of how the different topics affect adaptivity. Research question 2 is handled in the frame of reference.

Chapters 4 to 6 treat research questions 1, 3 and 4. The studies are presented with an introduction, the methods used, results and a discussion. Chapter 7 discusses the main purpose of the thesis and some other results that are important but are not research.

Chapter 8 gives suggestions for further work based on the studies that were carried out.
2 Future driver information

This chapter is a discussion about if and why there is a need for a change in driver information.

2.1 Functional growth

The design layout and use of information and entertainment systems in our cars have changed a great deal in recent years. Functional growth has been tremendous; systems have become more integrated, and most of the controls and displays are multifunctional, i.e. used in several of the systems (Broström, Engström, Agnvall, & Markkula, 2006).

Functional growth has been huge in the group of functions that aims to entertain the car's passengers. Twenty years ago the infotainment system contained AM and FM radio and a CD or cassette player. Now it is possible to have AM, FM, CD, USB, hard drives, Blue Tooth, streaming media, cell phones etc. The systems were first built in DIN size so, when a new system was desired, a DIN box with e.g. an equalizer was just added. One button had one function. When functionality grew, it was necessary to integrate functions and, today, most of the controls and displays have several purposes or are multifunctional. For instance, the volume knob controls sound volume for AM, FM, CD, phone etc.; the settings menu includes all the different systems menus.

![Figure 2. Cockpit by Volvo 240 (1989) and Volvo XC60 (2009)](image)

The driver information system that supports the driving task has not changed that dramatically and functional growth has been more moderate. The instrumentation looks about the same as it did 40 years ago. It commonly contains a large speedometer, a tachometer, a fuel and a coolant temperature gauge, trip and road
meter and some telltales. Quite recently trip computers and navigation systems have been integrated in the vehicles. Today and in the near future, more and more safety systems such as Forward Collision Warning (FCW), Lane Departure Warnings etc. will be introduced. It is expected that connectivity such as vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and vehicle to desktop (V2D) will also add heavily to this functionality.

Figure 3. Primary task information by Volvo 240 (1989) and Volvo XC60 (2009)

A good guess is that the primary information, also as entertainment, will be more integrated. Safety systems such as FCW will perhaps be integrated into navigation systems. What both systems do is prepare the driver for what may happen in the future, the navigation system on the strategic level and FCW on the operational level. The safety systems may also be more integrated with each other from a spatial perspective. Today, one system looks ahead, another looks in the blind spot and a third acts if the driver deviates from the lane. They all have different warning sounds and displays.

2.1.1 What drives functional growth?

Technology driven (Because we can)

Often, functional growth is driven by what the technical development can achieve rather than by the human needs. Norman (1988) describes a problem that is, more than ever, a burning question, namely creeping featurism. It is the tendency 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.

However, 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 to a higher degree easier 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. This was not possible when the gauges were physical.
Personalization is also possible, which can make information easier to understand or use. One obvious example is the tachometer in all cars, even those with automatic gearboxes, since it is too expensive for the car manufacturers to have two instrument variants, one for manual and one for automatic gear box. It is also possible for manufacturers to adapt to different market needs, an issue whose importance is indicated for instance by Lindgren (2009).

"Needs" driven

Rasmussen (1986), Michon (1985), Ranney (1994), Endsley, Bolté and Jones (2003) and other researchers have developed different models to describe drivers' behaviour. These models, which are discussed in detail in chapter 3, can be utilized in the identification of the different objective needs a driver has.

Another important factor when studying drivers’ needs is the different purposes of driver information. An increased awareness of safety, the effects of carbon footprint and a denser traffic situation are contributors to a need in change of driver information. Now and in the near future it seems likely that driver information will have an extended, more complete, purpose, which is to support safe, environmentally friendly (pollution), efficient (cost and time), legal and enjoyable (comfort, feel of control, fun etc.) transportation. This subject is discussed in more detail in Paper A and chapter 4.

Driving can be considered to be a complex socio-technical system where it is difficult to predict everything that might happen. In such a system, the driver often faces unknown problems, thus requiring reasoning and problem solving. It may also be argued that today's driver information requires reasoning or interpretation to be useful for decisions. It is indirect and shows mainly raw data, and not so often what to do or how to solve a problem.

"Wants" driven

An assumption in this thesis is that drivers may sometimes want to have a function for a more or less rational reason. The reason may be historical or traditional, because the driver likes to have information or to feel in control. From a manufacturer's perspective, such functions must therefore still exist even though it cannot be regarded as helping the driver to fulfil the objective needs. Several of the functions in today's instrument cluster would be difficult to explain if this were not the case.

Another viewpoint of "want" is acceptance of technology. If new technology is implemented it must be accepted or wanted by the users to be used and give an effect. Since the use of a system can be determined by perceived usefulness and ease of use (Davis, 1986), it is important that these factors are considered in designing the system.

2.1.2 Consequences of functional growth

Are there enough visual, manual and cognitive resources left for functional growth? If future driver information is implemented in a careless way, its potential to support the
driver's purposes may be reduced. An even worse scenario would be that the systems make driving less safe, less environmentally friendly and so on, through distraction.

Distraction is a voluntary or involuntary change in attention from primary driving tasks that is not related to impairment, where the diversion occurs because the driver is performing additional tasks and temporarily focusing on an object, event or person not related to primary driving tasks (Parliament of Victoria, 2006). It is obvious from this definition that information that aims to support primary driving tasks could also be distracting.

For instance, driving is a highly visual task (Wierville, 1993) and showing all the information created by functional growth simultaneously could potentially create visual clutter and inattention or distraction.

2.2 Situation awareness
While driving, the driver needs to be aware of the highly dynamic environment in which he or she is driving. Situation awareness (SA) breaks down into three separate levels: perception of the elements in the environment, comprehension of the current situation and projection of future status. SA is, according to Endsley et al. (2003), the engine that drives the train for decision making and performance in complex dynamic systems. SA, therefore seems to be a framework worth looking into.

2.3 Workload
Workload represents the cost incurred by a human operator in achieving a particular level of performance (Hart and Staveland, 1988) and too high a workload may affect drivers' performance negatively (de Waard, 1996) and can cause inattention, which is a large contributor to accidents. Moreover, there is evidence that underload can cause a shrinking resource pool (Young & Stanton, 2002), which may also affect performance in a critical situation.

Furthermore, high workload is one of the greatest threats against good SA (Endsley et al. 2003). Thus it seems that it is important to optimize workload.

2.4 Adaptive driver information - The solution?
What can solve functional growth, improve situation awareness and optimize workload and still support the driver's different goals of driving? Could adaptive driver information solve some of the issues? The aim of this thesis is therefore to explore and describe the different potential benefits of adaptive driver information.

One solution for reducing clutter induced by functional growth is to only show, or make more salient, the information needed or wanted for the moment and reduce, or make less salient, the information not needed. Workload could furthermore be managed or adapted in order to keep workload below the workload limit and above the too low limit. Workload can still become too high, of course, but this should at least not be induced by the driver information system.
However, adaptive driver information may also be associated with negative effects. Most of the problems identified in this thesis can be classified as automation induced errors. This type of error is hard to foresee (Bainbridge, 1983) and must therefore be handled carefully. This thesis will try to identify these problems and also give some suggestions for how to solve them.

2.5 Definition of adaptive

Driver information is adaptive if it adapts to external and internal circumstances. These circumstances may be context (location), traffic situation, driver's state, driver's skill, personality, historical reasons etc. In this thesis adaptive also means that the driver information is more or less changed automatically.

2.6 Research questions

The main purpose of this thesis is to investigate whether adaptive driver information has a potential to improve driver performance in fulfilling different purposes of driving, improve situation awareness (SA) and optimize workload. This can be further decomposed into four more specific research questions.

RQ 1. What are the purposes of future driver information and their relations to different functions?

RQ 2. What are the potential benefits and negative effects of adaptive driver information?

RQ 3. What information do drivers need and want throughout the driving task?

RQ 4. How can the negative aspects of adaptivity be avoided by design?
3 Frame of reference

This chapter discusses how others have dealt with the driver's needs and wants and the positive and negative aspects of adaptivity. An overview of different driver models also gives an understanding of the driver's needs in different driving situations and throughout the acquisition of skill.

Furthermore, good situation awareness includes sensing, perception and projection into the future and gives better driver performance. It is indicated here that there are several important input factors when designing for optimal situation awareness.

Workload, which can cause a reduction in driver performance if it is either too high or low, is another factor that could be optimized by adaptive driver information. Too high a workload also has a negative effect on situation awareness.

Automation is one of the biggest issues in a discussion of adaptive driver information. Automation of the information flow may reduce workload induced by interaction with systems in the car. This section describes some common automation induced problems and some general solutions.

Chapter 3 also serves as the answer to research question two (RQ2), which was: What are the potential benefits and negative effects of adaptive driver information? Literature studies were carried out, where most of the literature was found within the field of transportation and generally dealt with different safety issues. However, when studying automation, it was necessary to also look into a field with a larger experience of automation, the process and power industry.

3.1 Earlier work

Work on adaptive driver information 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.

The AIDE project (Engström et al, 2004) included adaptivity of an integrated HMI to the current driver state/driving context. The aim was to create an adaptive interface that was configurable for the different drivers’ characteristics, needs and preferences.
This thesis' perspective is slightly different from that of GIDS or AIDE. It includes workload management but has been extended to include also, for instance, the effects of low workload, what information a driver wants and needs, and an analysis of the purpose of driver information. The thesis also focuses more on what could be called "normal driving" conditions and looks also into other attributes than safety.

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 information about how to drive more safely, greener and so on may instead feel less inconvenient.

3.2 Driver modelling

There are several models that describe the driving task. In this section the driver model by Michon (1985), Rasmussen (1986), Ranney (1994) and Hatakka, Keskinen, Gregersen and Glad (1999) and a few motivational models by for instance Summala (2007), Engström, Markkula and Victor (n.d.) and Ljung Aust (2009) are described in the driver information context. The different models can serve as input to identify what support a driver needs throughout the driving task and the development of driving skill.

3.2.1 Michon (1985)

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 consisting of the actions with the vehicle controls: changing gear, braking, steering and so forth.

The upper levels influence the lower and, for safe, environmentally friendly, efficient, legal and enjoyable transportation, 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, among other things, 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 argued that most of the new systems such as ADAS mainly provide (or offer) support at the operational level and less on the strategic.

3.2.2 Rasmussen (1986)

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.
The different levels create different types of human errors that for instance can be categorized as in Generic Error Modelling System (GEMS) by Reason (1990).

However, 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.

### 3.2.3 Ranney (1984)

Ranney’s (1994) hierarchical control model (see figure 4) takes into account both the task structure and the human control structure by integrating the two frameworks mentioned above. Driving is seen as occurring on three different levels, which are similar to those in Michon’s (1985) model. Consequently, immediate vehicle control occurs at the operational level, actual manoeuvring takes place at the tactical level and trip decisions, route planning and general goals are set at the strategic level. Decisions made at superior level control behaviour at a lower level.

However, the different levels of decision making require different types of information. Skill based behaviour involves well learned procedures, rule based behaviour involves automated activation of rules or productions, and knowledge based behaviour involves active problem solving in novel situations in which no existing rules are applicable (Ranney, 1994).

From this framework it seems important not only to support the driver with correct information at every level of driving task demand but also to consider different levels of skill.

<table>
<thead>
<tr>
<th>Driving task demands</th>
<th>Driver Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic</td>
<td>Knowledge based</td>
</tr>
<tr>
<td>Navigation in unfamiliar area</td>
<td>Rule based</td>
</tr>
<tr>
<td>Choice between familiar routes</td>
<td>Skill based</td>
</tr>
<tr>
<td>Route used for daily commute</td>
<td></td>
</tr>
<tr>
<td>Tactical</td>
<td>Rule based</td>
</tr>
<tr>
<td>Controlling skid</td>
<td>Route used for daily commute</td>
</tr>
<tr>
<td>Passing other vehicle</td>
<td>Negotiating familiar intersection</td>
</tr>
<tr>
<td>Operational</td>
<td>Rule based</td>
</tr>
<tr>
<td>Novice on first lesson</td>
<td>Route used for daily commute</td>
</tr>
<tr>
<td>Driving unfamiliar vehicle</td>
<td>Negotiating familiar intersection</td>
</tr>
<tr>
<td>Vehicle handling in curve</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The combination of Rasmussen's (1986) and Michons (1985) and Michon’s different taxonomies by Ranney (1994)

### 3.2.4 Hatakka, Keskinen, Gregersen and Glad (The GADGET matrix)

The idea in a hierarchical approach is that failures as well as success at higher levels affect the demands on skills at lower levels. In Michon’s (1985) and Ranney's (1994) models, as well as in other models such as ECOM (Hollnagel, Näbo and Lau, 2003)
the top levels describe strategic tasks; for instance, if the purpose of the trip is changed, this also affects tactical decisions or how people operate the vehicle.

There is an even higher level above the strategic, however. Hatakka et al. (1999) made a further development of Michon’s (1985) hierarchy that includes this layer and developed it into a 3x4 matrix (see figure 5). The matrix looks very much like the Michon (1985) hierarchy but with the addition of a fourth level: goals for life and skills for living. It describes the knowledge about, and control over, how life goals and personal tendencies affect driving behaviour (lifestyle, life situation, peer group norms, motives, self-control, personal values etc.). In the other dimension, three columns describe the competencies that a driver needs. These are knowledge and skills, risk increasing factors and self-evaluation.

<table>
<thead>
<tr>
<th>Goals for life and skills for living</th>
<th>Knowledge and skills</th>
<th>Risk increasing factors</th>
<th>Self-evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving goals and context</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mastery of traffic situations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle manoeuvring</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. The GADGET matrix by Hatakka et al. (1999)

It is of course a great challenge for car manufacturers to affect the top layer, such as change a person's norms. Attempts have been made, not by manufacturers but by researchers, to affect for instance safety behaviour among young men by mental elaboration (see e.g. Falk, 2008). Safety or green driving coaches have also been suggested by for instance Birell, Young, Stanton and Jenkins (2008) to give more long term effects on driver behaviour.

3.2.5 Motivation

Linked to this fourth level, goals for life and skills for living, are different theories about motivation. The motivation to drive more safety (on the tactical and strategic level) may depend on the driver's motives, self-control, personal values etc.

There are several theories about how drivers handle risk, for instance, the hypothesis of risk homeostasis. Wilde (1982) claims 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 a corresponding rise or fall in risk somewhere to bring the overall risk back in 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". This mechanism results in a comfortable state and is called "comfort through satisfying".

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Heavily influenced by Summala is for instance Ljung Aust's (2009) proposed 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 exceedance (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. The second category (2) represents functions which detect and warn when a joint driver vehicle system (JDVS) comes close to the safety zone boundary. The third category (3) represents functions for situations where the JDVS in a sense is balancing on the safety zone boundary. The fourth category (4) represents functions addressing the part of the trajectory that goes beyond the safety zone boundary.

Figure 6. Illustration of the role of active safety functions according to the framework of Ljung Aust (2009)

This thesis treats the information provided up to level 1. The purpose is to change the behaviour by advisory information in such a way that a warning rarely occurs. In addition, it also seems reasonable to use this idea for other areas than safety. For instance, there may be a comfort zone also for fuel consumption, for illegal driving and for efficiency etc.

3.2.6 Information processing

It is not an exaggeration to say that the famous model of information processing (Wickens & Hollands, 1992, 1999) has had the greatest impact on research in the field of engineering psychology. It is a model that describes sensory processing, perception, cognition, memory and response selection and execution.
Information flow

The stimuli access the brain through the different sensors. This step has an enormous impact on the quality of the information that reaches the brain. If the signal is weak or the surrounding noise is too strong, errors may occur in the subsequent steps.

The raw sensory data need to be interpreted or given meaning. This step is called perception. There are two types of perception: bottom up and top down. Bottom up requires little attention and is driven by sensory data and data from the long term memory about expected events. Top down processing means that almost all information comes from the expectations due to low quality of sensory data. For instance, we can not see what is behind the next curve (Wickens and Hollands, 1999). This is a risky strategy since the expectations can be wrong.

Cognition can be hard to distinguish from perception, but the important distinction is that cognitive operations generally require more time, mental effort or attention. Cognition is rehearsal, reasoning and image transformation.

The understanding achieved by cognition or perception of a situation often triggers an action. This is divided into response selection and response execution. When an execution has been performed, new stimuli are produced.

Attention

The "ellipse" above the different phases in figure 7 represents the supply of mental resources. This attention resource pool is used for selection of attention, working memory (for cognition), response selection and response execution, which all require attention resources.

Attentional resource theories make a common basic assumption about performance: if demands exceed resource capacity, performance degrades.
Early research suggested that attention was related to psychological arousal (Kahnemann, 1973) by long term fluctuations in mood or age (Hasher and Zacks, 1979; Humphreys and Revelle, 1984), but most applied research on attention has implicitly assumed that the size of the resource pools is fixed (Wickens and Hollands, 1992).

However, Young and Stanton (2002) suggest that the attentional capacity can change size in response to changes in task demands. As such, the performance reduction associated with mental underload can be explained by a lack of appropriate attentional resources. This theory, the malleable attention resource theory (MART), is further discussed in the workload section.

The information process has been criticized by many researchers (see for instance Engström and Hollnagel, 2007) for its description of people being reactors rather than actors. However, this part has been given less emphasis in the more recent versions (Wickens and Hollands, 1999), and the different stages can still be used as a model to describe the complexity and limitations of human performance.

### 3.2.7 Multiple resource theory

A development of the information process with two extra dimensions, modalities and codes gives the multiple resource theory.

The multiple resources theory below (Figure 8) suggests that the three dimensions (stages, modalities and codes) are to some extent sovereign of each other (Wickens and Hollands, 1999). The vertical modality dichotomy 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. Finally, the stage of processing dimension is represented with only two resources rather than three, suggesting, as shown in figure 8 below, that perceptual and cognitive processes demand the same resources, different from those involved in action selection and execution.
Figure 8. The multiple resource theory

An important implication of the processing codes distinction is the ability to judge when it might or might not be favourable 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.

Another mode of communicating with the driver is by a haptic interface. Can haptic information be utilized instead of visual information to reduce visual work? 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 replace it (Rydström, 2009).

### 3.2.8 Engström

Attention is very important during driving and inattention is one of the largest contributors to accidents (Dingus et al., 2006). The traditional information processing models presented above tend to view attention selection as a consequence of limited capacity. However, Engström et al. (n.d.) with their action oriented perspective, view selection as the main phenomenon of interest. Their attention selection model describes the selection of attention being part of a larger range of adaptive behaviours with the general purpose of maintaining sufficient perceived safety margins to potential obstacles and other hazards.

The model proposed by Engström et al. (n.d.) contains three main components: (1) sensory and effector systems interacting with the environment; (2) competing and cooperating schemata, implementing routine actions and action patterns; and (3) supervisory control, which may be used to bias the schemata when demanded by
stabilizing inherently weak schemata, binding together normally unrelated schemata and overriding inherently stronger schemata when needed. To create an understanding of what schemata is, it is best to look at the definition by Neisser (1976).

"A schema is that portion of the entire perceptual cycle which is internal to the perceiver, modifiable by experience, and somehow specific to what is being perceived. The schema accepts information as it becomes available at sensory surfaces and is changed by that information; it directs movements and exploratory activities that make more information available, by which it is further modified". (Neisser, 1976)

3.2.9 Discussion of driver models

The different driver models indicate that the driver needs support on different levels in the driving task and throughout the development of skill. There is an unused potential in the knowledge based and strategic information. Furthermore, drivers need salient and interpretable stimulus from the world around them and may need cognitive support. Attentional resources are limited, and thus the workload may need to be reduced. On the other hand, long periods of low workload can also reduce driver performance. Thus, an optimization of workload is instead ideal.

Attention selection is governed by the environment, different schemata and expectations. It therefore seems reasonable that both top down processing and the development of unbiased schemata can be supported by supervisory control. Moreover, even though driving is visually demanding, most of the information is visual. There seems to be potential in utilizing Wickens and Hollands (1999) multiple resource theory and moving towards less visually demanding information.

Motivation also seems to be an important factor. Strategic decisions are influenced by the driver's values in life, and safety margins and risk behaviour are determined by a comfort level.

Strikingly few of the items in any of the models are supported by the car itself or by society after formal driver education and throughout the development of skill. Both society and the manufacturers seem to rely on the driver to keep everything up to date. For instance, how do car manufacturers and society communicate the different new support systems?

To our knowledge, driving information has not yet focused on the level above the strategic. However, if this level were affected by the information given from the car, it may also influence the long term effects.

Furthermore, the information is often indirect. The driver needs to interpret the information before it can be used to make decisions, and this requires attentional resources. For instance, given the distance, speed must be calculated into duration, the tachometer requires knowledge of torque curves and so on to be useful for green driving and so on. Thus, there seems to be a potential for being more direct.
3.3 Situation awareness

SA consists of: perception of the elements in the environment, comprehension of the current situation and projection of future status and in a review of commercial aviation accidents, 88% of those with 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 et al., 2003).

Even though the concept has been criticised extensively (e.g. Flach 1995) it contains several useful ideas. – for instance that people make projections of future events based on their actual mental model of the situation, act instead of react and choose to perceive which indicates that motivation is involved (Vogel, 2002).

The technological development with new and cheaper sensors may make it possible to improve the driver's situation awareness and by that improve drivers' performance. But what governs which information the driver should have at hand while driving to obtain a better SA? What are the input factors? What should be thought of when developing a system to support SA?

3.3.1 What should govern SA (input factors)?

Alfredson (2007) suggests that an ideal SA supporting system development 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. Drivers' tasks can also be considered as an input factor (Hoedemaeker and Neerincx, 2007).

3.3.2 What should be governed to improve SA (output factors)?

It is a rather intuitive thought that a driver needs different information in different situations. For instance, a driver may not need a 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 be inappropriate for specific situations. Complex, visual or cognitively distracting feedback information about how to drive safer or more environmentally friendly may be more suitable before or after driving. Likewise, distance alert or gear change advisors are more useful while driving.

The output factors could be explained as what should be communicated and when. There are several hundreds of warnings, information telltales and text messages in a modern car. There are also gauges, trip computers, navigation systems and head up displays and so on. Some of the information is provided by just looking out of the car and some are provided by the road authority through road signs.
To create a matrix with all the input factors on one axis and all the functions on the other would probably be very difficult and not very lucid, especially if it is likely that the different input factors are divided into subfactors. For instance, the contextual prerequisites may be divided into different road types, different intersection types and so on. The number of combinations would probably be infinite.

An alternative strategy would be to keep the number of modes to a minimum. This strategy would produce greater discrepancies between task demands and the appropriate automation mode at any moment but would reduce the need to keep track of a rapidly fluctuating set of operating procedures (Scerbo, 1994).

The issue is therefore to make priorities between the different input factors. One of the future questions must therefore be to find the most important input factors for the different purposes of driver information.

### 3.3.3 What affects SA negatively

Even though designers have the intention to support SA there are also several threats that may have a negative impact on SA. Endsley et al. (2003) mention attentional tunnelling, requisite memory trap, workload, anxiety, fatigue and other stress factors, data overload, misplaced salience, complexity creep, errant mental models and out-of-the-loop syndrome as potential threats of SA.

These are challenging to avoid, but by bringing these threats to light it is possible to take the first step towards an SA oriented design.

Workload is in itself a very important factor for safety and it has therefore been honoured with a section of its own below.

### 3.3.4 Discussion of SA

SA, which seems to be one important factor to work with, is governed by several input factors. Current vehicle status, situational conditions, contextual prerequisites, individual status, historical behavioural data and the driver's task should be considered when a decision is taken about what should be communicated to a driver and when.

It may be assumed that some of the input factors are easier or cheaper to measure than others. For instance, map data could more easily be used to decide context. Situational conditions, individual status and operator's performance are more difficult to measure and interpret, however.

This makes knowledge about which of the input factors that has the largest impact on SA very important. This has not yet been investigated. In this thesis one assumption is that the context is important. However, it has not been verified that this is more or less important than any of the other impact factors. Further research needs to establish which of the input factors are the most influential.
SA may provide the information the driver need to better perceive the elements in the environment, comprehend the current situation and support projection of future status. Much of this information can be provided the driver by the car’s information systems but needs to adapt to the different input factors.

An adaptive driver interface can for instance augment reality when needed, support decision making or explain hazardous situations and give feed forward information about coming events.

### 3.4 Workload

One of the main thoughts about adaptivity 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 workload.

Previously, researchers and designers have mainly focused on reducing workload since high workload affects driving performance (de Waard, 1996) and reduced performance can lead to accidents. One example of how workload affects driver performance was given by Alm and Nilsson (1994), where it was shown that reaction time was prolonged and headway keeping performance was reduced when using a mobile phone while driving.

When discussing what too high workload is, it is important to note that mental workload is both task dependant and person specific (de Waard, 1996), i.e. the same task demands do not result in an equal level of workload for all individuals. It is therefore not only necessary to reduce the task complexity as much as possible but also to consider individual differences when creating adaptive systems. Some may have difficulties with a relatively low workload and therefore need more support, while others would be annoyed by the same level of support. This also points in the same directions as for SA, that individual status and historical behavioural data are important.

Information can also be described as a reduced level of uncertainty (Wickens and Hollands, 1999). The exclusion of visual information could therefore also increase uncertainty and workload. This means that it is possible that the driver can lack information in relation to the driving task and individual driver goals (Salmon, Regan, Lenne, Stanton and Young, 2007). Therefore, reducing visual tasks is not the only way to reduce workload. Given that the information is useful, adding visual tasks, or preferably information in another modality, can thus potentially reduce workload.

It has also been proposed (Young & Stanton, 2002) that resources may actually shrink to accommodate any demand reduction, in contrast to the "work expands to fill the time available" tenet. This could explain the degradation of attention and performance observed in low demand tasks. If the maximum capacity of an operator has been limited as a consequence of the task, it is not surprising that the operator cannot cope when a critical situation arises. The malleable attentional resources theory (MART)
therefore potentially explains why mental underload can lead to performance degradation (Young & Stanton, 2002).

Driving is a highly visual task (Peacock, Karwowski, 1993). 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 single most important source of information for the driver (Wierville, 1993)

When designing display content 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 legible 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 dwell is nearly twice as long as an expert’s on the information rich attitude directional indicators (Wickens and Hollands, 1999).

It is therefore likely that drivers will spend more time fixating complex displays with high information content, which could be a reality when functional growth occurs. This is time that otherwise could have been spent looking at the road. An adaptive interface could possibly reduce clutter since only the necessary information is available.

On the other hand, an adaptive change between, for instance, different modes of information could reduce the likelihood of developing expertise in comparison with the case in which the information never changes. This is another reason to keep the number of modes low for the driver.

**Manual**

In this thesis, manual work is about how much effort the driver has to put into hand or foot work. It could be argued that the more the hands are on the steering wheel, the more prepared a driver is, should an accident occur. If the transition time is long, this may affect the time it takes to initiate an action to avoid an obstacle or to brake.

### 3.4.1 Managing high workload

As mentioned earlier, data overload could be a problem for the maintenance of SA in different driving situations. In these situations, the rapid rate at which data change creates a need for information intake that can outpace the ability of a person’s sensory and cognitive system to supply that need. As people can only take in and process a limited amount of information at a time, significant lapses in SA can occur. The human brain becomes the bottleneck (Endsley et al, 2003).

It is possible to avoid the bottleneck problems and to manage workload. In Volvo car's Intelligent Driver Information System, IDIS (Broström et al., 2006), the workload is calculated by a set of rules and, if the workload value is high, some information is blocked or postponed. IDIS uses sensor data such as steering wheel angle, acceleration
or brake data from the car but, according to Hoedemaeker and Neerincx (2007), the final goal of a central workload management system should be to adapt to: the state of the driver, the vehicle and the surrounding environment and the different in-car tasks. This is strikingly similar to what Alfredson (2007) stated about an optimal SA support.

According to Woods and Hollnagel (2006), it is possible to support an optimal workload level in four different ways: shed load, do all components but do each less thoroughly, shift work in time to lower workload periods, or recruit more resources.

**Shed load**

It is possible to completely block information that is not useful to the driver in a particular situation.

**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 driver performance degrades. A way to reduce workload to a handy level may therefore be to do things less thoroughly. For instance, look less for obstacles or hazards. It could be argued that this strategy of dealing with workload should be avoided since it may cause accidents.

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

Workload could either be moved back or forward in time when it is too high. For instance, there is a possibility to provide the driver with information about the future during periods of low workload or to postpone information to the driver in critical situations. Piechulla, Maysr, Gehrke and König (2003) conclude that their results in a preliminary system showed a reduction of 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. IDIS belongs to this category since it postpones phone calls or less important messages to the future when the workload is lower.

**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 and performance has been reduced.

Changing the information content of an adaptive driver information display may, if done manually, add to workload. Instead, it would be possible to reduce workload by changing the information automatically.

**Multiple resource theory**

In addition to the four ways of dealing with workload presented by Woods and Hollnagel (2006), it would also speed up processing to redundantly code a target across modalities (Wickens and Hollands, 1999). Therefore, one way of reducing
workload is to give drivers information in other modalities than what are used for driving. Driving is a highly visual and manual task and it could therefore be suggested to use haptic or acoustic cues to support the driver. Furthermore, the interaction with the vehicle could be less manual to allow the driver keep the hands on the steering wheel.

3.4.2 Managing low workload
As well as managing high workload it seems important to manage low workload, and evidence is accumulating that simply reducing demand is not necessarily a key to improving performance.

For instance, contrary to the notion that interactive media necessarily cause unsafe driving, Takayama and Nass (2008) suggest that interactive media may be helpful for drowsy drivers but not harmful to non-drowsy drivers. These findings present a more nuanced view of the situation of interactive media in cars, extending existing research to include levels of media interactivity in cars. It is important for researchers to empirically investigate the risks of interactive media in cars, but it is also important to see if and how interactive media might improve driver safety.

Malleable resource theory
The malleable attentional resources theory (MART) (Young and Stanton, 2002) is, as mentioned before, a potential explanation to why mental underload can lead to performance degradation. Consequently, it may be possible to increase workload during low workload conditions in order to increase or at least maintain the driver’s performance.

A recent study by Gershona, Ronen, Oron-Gilad and Shinar (2009) 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, and their benefits may increase with the advent of in-vehicle systems that relieve the drivers of more and more components of the driving task.

3.4.3 Discussion of workload
It seems to be a challenging balancing act to keep the workload between too high and too low a level. Researchers have until recently focused on managing too high a workload but evidence is gathering that also too low a workload should be fought.

An adaptive system could reduce workload by either blocking information, moving workload in time, adding resources or changing mode of communication. It also seems reasonable to believe that the reduction of performance due to low workload can be managed by a temporary increase in workload created by, for instance, the supervisory control system.

In particular, it seems that information about the future or feed forward information has potential.
For instance, a study by Alm and Nilsson (2000) shows strong positive effects of feed forward by incident warning systems (IWS). However, the study also shows that before a decision is made concerning what type of IWS is needed in a certain situation, it is necessary to know what type of incident will occur and what types of driver actions can be performed to avoid negative effects of the incident.

Another example would be to give the driver information much earlier about a future complex intersection instead of giving the information just before the intersection, as most navigation systems do today.

This may have at least two but perhaps even three benefits:
First, the driver is prepared when entering a complex driving situation and can concentrate on the operational (for instance, to avoid pedestrians) or tactical task (such as choosing lane), rather than the strategic (where to go).

Secondly, the driver's performance level is higher according to the malleable resource theory, which implies that the resource pool shrinks to accommodate the demand reduction in low demand tasks (Young and Stanton, 2002).

A potential third benefit is to present information by supervisory control in order to affect the selection of attention (Engström, et al., n.d.), for instance, if the driver’s attention is governed by an imperfect schemata over hazards.

However, if designed in a poor manner, for instance, by providing too much information that is necessary to keep in working memory, or not knowing the consequences of the information, more information may instead lead to high workload or other unwanted effects.

Furthermore, it seems rational to keep the number of operational modes to a minimum due to a development of skill that influences the efficiency in the visual behaviour.

3.5 Automation

In the workload section of this thesis it was shown that adding resources could reduce workload. One way of adding resources is to automate different driver tasks and an adaptive systems that changes information due to context, situations and other input factors could be described as automation.

The automation may be controlled within the continuum between manual and automatic (See e.g. Parasuraman, 1996). Each level of automation has its own pros and cons. In manual control the driver is in command of what is shown and therefore nothing, or at least less unexpected events, happens. For instance, if the driver wants to reduce the workload in a difficult situation, he or she first has to interact with the information system and tell it not to present unimportant information. The driver would understand why some information was not shown but the interaction would, of course, add even more workload.
An automatic approach with a dialogue manager, for instance, does not directly add to workload but may instead create so called automation induced surprises. It is not yet easy to say which of the automation induced surprises described in the next section will occur in the dialogue manager context. The problems have mainly occurred in the process industry and aviation, where automation is common, but are likely also to occur in vehicles as automation becomes more and more common.

This section will discuss automation on a somewhat higher level. The reason is that there is growing interest in the automation of driver tasks, not only in automation of driver information but also in more complete automation such as autonomously driven vehicles.

### 3.5.1 Automation induced surprises and issues

Much has been written about the difficulties of automation. Bainbridge (1983) concluded that automation may have some unwanted side effects and may actually create new problems. Stanton and Young (2000) discussed driving automation and raised issues such as trust, mental workload, locus of control (Rotter, 1966), 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 on 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 errors are discussed in this section.

#### Function allocation

A classical question is "who is doing what?" What should the driver do and what should the car do? Long MABA-MABA lists (Men Are Best At – Machines Are Best At) lists have been created throughout the years. However, Dekker and Woods (2002) argue that substitution based function allocation methods (such as MABA-MABA lists) cannot develop human-automation coordination. Instead they propose that the more pressing question on human-automation coordination is “how do we make them get along together?”

#### Trust

**Under trust**

There seems to be a good deal of scepticism about automation among its users and confidence, both in oneself and the automation, has an impact on its usage (Lee & Moray, 1992, Muir, 1987). According to Muir and Moray (1996), the amount of feedback sought from an automated system by human operator is directly related to the degree of trust they have in it to perform without failure. To be more specific, operators will use automation when trust exceeds self-confidence but will revert to manual control when the opposite is true.
**Overtrust**

Too much confidence creates with it another set of problems. Once a sense of trust has developed and an automatic system has become an accepted method of operation, there is a potential danger that individuals will become too reliant on the automation. This may lead operators to be less willing to evaluate or even monitor the automated activities, a situation that has been described as automation induced "complacency" (Parasuraman, Molloy and Singh, 1993). This has of course a relation to the different models about motivation described earlier.

**Skill degeneration**

If one of the agents in the system is doing one task all the time, it is difficult for other agents to develop skills or, if they have already developed a skill, to maintain the skill level. Wickens and Hollands (1999) argued that manual skills may deteriorate in the presence of long periods of automation.

**Mode errors**

Mode errors occur when devices have more than one mode of operation and the action appropriate for one mode has different meanings in other modes. Mode errors are foreseeable anytime equipment is designed to have more possible actions than it has controls or displays, which is common in cars, so the controls must do double duty (Norman, 1988).

If information in adaptive driver information changes without the influence of the driver, the display has more than one duty and may therefore also end up asking the same question as the title of Sarter and Woods (1995) article. It is expected that this can be a large source of problems when driver information flow is automated.

**Locus of control**

Locus of control refers to how much a person blames the causes of events on internal or external factors (Rotter, 1966). People with a high internal locus of control ("internals") tend to believe that most things that happen are their own fault, regardless of the objective cause. On the other hand, those with a high external locus of control ("externals") tend not to accept blame for anything, preferring instead to believe in environmental reasons, even if they have clearly instigated an event. People with external locus of control may blame the different systems in the vehicle despite the objective cause.

**Vigilance**

There is a great deal of research on human vigilance that indicates that human monitoring performance is prone to error when monitoring must be performed for long, uninterrupted periods of time (Davies & Parasuraman, 1982).

Research on vigilance has shown that detection of low probability events is degraded after prolonged periods on watch (Davies & Parasuraman, 1982). One might predict, therefore, that human operator detection of a failure in the automated control of a task,
which is likely to be an improbable event, would be very poor after a prolonged period spent under automation control.

**Monitoring behaviour in automated systems**

It is proposed that monitoring might be efficient when it is the only task, with or without computer aid (Parasuraman et al., 1993), but that, when operators are engaged in other simultaneous tasks, monitoring of an automated task is poorer than that of the same task under manual control.

**Workload**

One idea behind automation is that it should help to reduce mental workload. However, evidence shows that this does not necessarily happen. Instead, Woods (1994) argued that automation simply changes how work is accomplished. In fact, Wiener (1989) claimed that the introduction of automation sometimes even increases workload. He cautioned that, too often, automated systems may operate well under periods of low workload and become a burden during high workload periods.

Others argue that automation removes the operator from the "loop" leading to decreases in situation awareness (Sarter & Woods, 1992). Consequently, overreliance on automation may make the operator less aware of what the system is doing at any given moment, leaving him or her ill-equipped to deal with a failure of automation.

Wickens and Hollands (1992) stated that automating a function increases the number of decisions from one to three a human operator must make in diagnosing a potential system malfunction for instance, if an automated system monitors the doors of a car to ensure that they are closed during the trip. In the event of a failure indication, the driver must decide whether it reflects a dangerous condition (open door), a failure in the automated monitor or a malfunction in the display indicator of the automated system.

### 3.5.2 Managing automation induced errors

**Adaptive Automation**

Adaptive automation represents an alternative to static automation in which computer assistance or task allocation between human operators and computer systems is flexible and context dependent rather than fixed (Parasuraman and Hancock, 2001). The basis for the adaptive automation argument is the intrinsic trade-off between workload and situation awareness that results as the level of automation is varied. Given an assumption that automation should be kept at lower levels unless high workload precludes effective human performance, adaptive automation will then optimize the contribution of both human and machine in a workload varying environment (Wickens and Hollands, 1999).
The task manager assigns workload to either the automation or the human. The task manager could be an automated, human or cooperative enterprise (Wickens and Hollands, 1999).

Previous evaluations of adaptive automation have focused on the performance and workload effects of either (a) adaptive aiding of the human operator or (b) 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 adaptive driving information perspective. Of course, the information can be changed manually in low workload conditions and automatically during high workload, but would not the adaptive automation instead create new questions such as what to adapt, how to infer and who decides? (Wickens and Hollands, 1999).

**Team player approach**

Some of the automation induced issues could be reduced by making the agents within the cognitive system co-operate more and better. Dekker (2002) concludes that system developers should abandon the traditional "who does what" question of function allocation and instead make humans and automation get along together.

Woods and Sarter (1999) put several questions about automation in cockpits for aircrafts. What should we learn from the problems? Do they represent over-automation or human error? There might also be a third possibility: that they represent coordination breakdowns between operators and the automation.

Woods and Sarter (1999) argue that the problem is either about over-automation or human errors. Instead of reducing automation or designing mainly to reduce errors, it is suggested that it is possible to tame the complexity of a system by making the automation act like a team player. Young, Stanton and Harris (2007) 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 and Woods (1995) 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 serious, the need to shape the machine agents into team players is critical (Christoffersen and Woods, 2004).

All of this sounds reasonable. However, the problem is how do we create car systems that act as team players? Klein, Woods, Bradshaw, Hoffman and Feltovich (2004) outlined ten challenges for making automation components into effective "team players" when they interact with people (see figure 10).

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<thead>
<tr>
<th></th>
<th>Agents must fulfil the requirements of a basic compact to engage in common grounding activities.</th>
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<tr>
<td>2</td>
<td>Agents must be able to adequately model the other participants’ intents and actions vis-à-vis the state and evolution of the joint activity.</td>
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<td>3</td>
<td>Agents must be inter-predictable i.e. be able to observe and correctly predict future behaviour of teammates.</td>
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<td>4</td>
<td>Agents must be directable.</td>
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<td>5</td>
<td>Agents must be able to make pertinent aspects of their status and intentions obvious to their teammates.</td>
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<td>6</td>
<td>Agents must be able to observe and interpret pertinent signals of status and intentions.</td>
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<td>7</td>
<td>Agents must be able to engage in goal negotiation.</td>
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<td>8</td>
<td>Planning and autonomy support technologies must enable a collaborative approach.</td>
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<td>9</td>
<td>Agents must be able to participate in the management of attention.</td>
</tr>
<tr>
<td>10</td>
<td>Agents must control the costs of coordinated activity.</td>
</tr>
</tbody>
</table>

Figure 10. Ten challenges for making automation components into effective "team players", according to Klein et al. (2004)

Furthermore, Christoffersen and Woods (2004) conclude that observability and directability are the keys to fostering a cooperative relationship between the human and machine agents in any joint system.

It seems that the nature of the different "challenges" is very visual and requires a great deal of interaction and reasoning. Thus, since the driving task also is very visual; the challenges are even bigger for car system designers in automating driver tasks.
3.5.3 Discussion about the automation

Full vehicle automation is predicted to be on British roads by 2030 (Walker, Stanton and Young, 2001). When or if this occurs, it is likely that many of the problems that have been stated above must be dealt with. Today, when automation is limited to Advanced Driver Assistance Systems (ADAS) such as Forward Collision Warning, blind spot detection, lane keeping aid, lane departure warnings, Collision Mitigation, Driver Alert and a few support systems, the knowledge about automation induced problems is limited, even though some have mentioned complacency as a possible problem.

In adaptive driver information it is likely that some of the issues stated above occur but some do not. For instance, mode errors and low trust problems are likely to occur if the design is not thoughtful, while too high trust or vigilance problems are not expected at all, or only to a small extent. It is difficult, at this stage, to make a more accurate estimation of how likely the different errors or issues are. Since automation by nature creates new human strengths and weaknesses, often in unanticipated ways (Bainbridge, 1983), it is preferred to keep attention on all of the error types throughout the whole project.

3.6 Summary of frame of reference

Driver models have been described, and it seems that driver information not only has to be sensed or understandable. It also has to support strategic decision making and knowledge based behaviour. A challenge would also be to affect the layer above the strategic, the layer called "goals for life and skills for living" which also influences risk behaviour. Driver information also has a future in other modalities than the visual.

Situation awareness, which contains perception of the elements in the environment, comprehension of the current situation and projection of future status, also plays a role in making the driver perform better.

Driver models, workload, situation awareness and automation are probably the topics that most influence adaptation. Within each of these topics there are possibilities to vary different parameters. Information content could be varied to fit different input parameters such as context or driver state, and workload could be varied by shedding, moving load in time or automating tasks.

The level of automation could also be varied between completely manual and completely automatic. Even the level of automation could be automated, as in adaptive automation.

Automation could optimize the driver's workload by managing the driver information. However, automation could be associated with problems such as trust, mental workload, locus of control, mode errors, driver stress and mental representation. It is not yet known how often or how much these problem will occur when introducing adaptive driver information.
One way of dealing with automation is to have adaptive automation. Another is to make the different agents within the system become team players. Team players show intention, have common goals, are directable, are engaged in goal negotiation, are observable and so on.
4 What are the purposes of future driver information and their relations to different functions? (Paper A)

4.1 Introduction
As has been described above there is a great potential to improve driver information. A lot is missing and a lot is there only due to tradition. It seems that there is a need for manufacturers to re-think what they are doing and why they are doing it. The first research question was therefore to identify the purposes of future driver information and their relations to different functions.

Paper A therefore identifies 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. These strong or weak relations could then influence the design of future driver information in cars.

4.2 Method
An Ecological Interface Design (EID) approach was utilized. In EID, Cognitive Work Analysis (CWA) can be regarded as an EID method. The first step in CWA, called Work Domain Analysis (WDA), was used. The WDA is a structured way to create links between purposes of driver information and the different components of the driver information.

4.2.1 Apparatus
A software (the CWA-TOOL v1.0) developed by the Defence Technology Centre in the United Kingdom was used to create the decomposition.

4.2.2 Participants
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 work domain analyses. The main work was done by the author.
4.2.3 Study Constraints
Driver information can be received in many ways, e.g. traffic signs, traffic message channels (TMC) etc. However, this study was limited to what a private car manufacturer could do to provide different kinds of information. The system is defined as a "private car driver information system". Driver information system means that the main purpose of the system is to support the driver's goals, e.g. to navigate or maintain speed but also to be environmentally friendly etc. Driver information was not only limited to within the car. Before and after driving were also included.

Most of the information needed came from the research team members and from Volvo Cars' strategy documents.

Several iterations were performed with e.g. focus groups and interviews to create the decomposition.

When the decomposition was made, the different links were followed and discussed throughout the decomposition. The most interesting findings, the weak relations and the gaps were noted and discussed in order to see the implications for future design.

4.3 Results
The WDA recognized five functional purposes of driving information: to support safe, efficient, environment friendly, legal and enjoyable transportation.

The "functional purpose" was further 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" identified 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.

In the design implications part it was concluded that planning could be improved in comparison with today's systems through for instance, pre- and post-trip information. The navigation system could be improved by features such as route optimization based on safety or carbon footprint.

4.4 Discussion
4.4.1 Results discussion
It seems that the results may be biased depending on the choice of team members. The results are highly dependant on the members’ experience and creativity in the research group. It could also be argued that the functional purposes' importance could be different at different manufacturers depending on the ideology within the company. For instance, a CWA for a company with other goals may have other functions. However, no weight between the different functions has been made, which makes the decomposition more generic.
A general conclusion is that the decomposition also showed the importance of a designer to ask the question "why?" when designing a product.

4.4.2 Methodological considerations

Choice of method

The first research question was "What are the purposes of driver information and their relations to different functions?". A method was needed that identified the purpose of systems in a complex socio-technical system, where it is difficult to predict everything that might happen in the system, such as traffic. Furthermore, it was necessary to have a method that supports 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 activities 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).

A good and very early example of how constraints work in a traffic environment was created by Gibson and Crooks (1938). The "safe field of travel" describes the constraints within which the driver must be in order to drive safely.

Cognitive Work Analysis (CWA)

CWA, which can be regarded as an EID method, is divided into five phases. Work domain, control tasks, strategies, social organization and cooperation, and worker competencies represent 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.)

The majority of the CWA work has been performed in the process or power industry (see for instance Vicente, 1999). However, there are several studies that have used CWA to study vehicle design implications. The first step, work domain analysis, in CWA was used by Salmon et al. (2007) to study Intelligent Transport Systems (ITS). Birell et al. (2008) used CWA to develop a technological device which will encourage drivers to drive in a safer and greener manner through on-board advice and post-drive feedback. Seppelt and Lee (2006) applied ecological interface design (EID) to create a visual representation of Adaptive Cruise Control (ACC) behaviour. Jenkins et al. (2007) used the first steps in CWA and developed a new approach to designing lateral collision warning systems, and Lindgren (2008) created an advisory ADAS interface with the use of EID.
Complexity
The complexity of the WDA was enormous since all (not warnings) of the functions were included in the study. It would have been easier to include fewer functions. However, one of the purposes was to identify weak links and this would not have been possible without a complete decomposition.

This was also the reason why the abstraction decomposition space, described by e.g. Naikar et al. (2005), was limited to the complete system. Of course it would have been possible to further break down the systems into subsystems, such as traffic signs 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.
5 What information do drivers need and want throughout the driving task? (Paper B)

5.1 Introduction
Research question three was “What information do drivers need and want throughout the driving task?” The aim of this study was therefore to investigate what information people need and want from the car in different contexts and to what extent there is a consensus about the function. The context is defined as what the road environment looks like independent of other road users. For instance, an intersection or a roundabout could be a context.

5.2 Method
Based on the aim, an interview procedure with a qualitative result was created. Each step was carefully designed.

1. Preparation.
   a. Contexts were decided by Human Machine Interaction (HMI) and safety experts at Volvo Cars and Luleå University of Technology.
   b. The Functions were specified by HMI experts at Volvo Cars.

2. Participants.
   33 Swedish private car drivers, 14 men and 19 women, recruited in the Gothenburg area in Sweden, participated. The subjects were on average 42 years old; the minimum age was 20 and maximum age 69.

3. The interviews mainly took place at Lindholmen Science Park in Gothenburg but some of the interviews were located at the participant’s home for reasons of convenience.

4. The subject was welcomed and asked to sit down in front of a board with pictures describing the context that was to be discussed (Figure 12).

5. The subjects were given instructions:
   a. Look at the pictures on the board (see Figure 12) 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)?
   f. Think of your emotions in this kind of context.
6. The subjects were left alone for five minutes.
7. A simulation interview took place. 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 mention any information that you would like to have from the car in this type of context?
8. A grading of physical functions was then made. Notes were taken.
   a. The subjects were asked to grade the function from 1-5 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 subject 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 subject took a card on which the physical function was printed from a randomly mixed stack of cards. The subject read the physical function and the number (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 Figure 12).
   d. If the subject made a comment, notes were taken.
   e. The subjects were then shown gratitude for their participation.
9. A Contextual Activity Template (CAT) was created from the grades and the notes. The CAT is a matrix with the functions in one dimension and the contexts on the other (See figure 13). This work was done by the research team. A software (The CWA-TOOL v1.0) developed by the Defence Technology Centre in the United Kingdom was used to create the CAT.

![Figure 12. The apparatus used to illustrate the contexts. On this particular occasion straight highway driving was illustrated.](image)
5.3 Results
The decided contexts were: Before and after driving, Car park, Highway intersection, Straight highway driving, Queue and City intersection.

That drivers want or need different functions in different contexts is rather intuitive and this is also indicated in the results. One way to find out whether drivers want or need different functions in different contexts is to follow the function through the different contexts, for instance, the function "show where the roads are heading in the next intersection". This particular example was described as a possible scenario for how the information is exchanged during a trip.

The different contexts’ perceived needed and wanted information was then sorted by most important, least important and high and low consensus. The CAT was an interpretation made by the research team of the grading, the waste bin and the open ended answers for each function. The bars in the CAT show where a function "typically should be" and the dotted line where it "can be".

![Figure 13. A part of the Contextual Activity Template (Naikar et al., 2005)](image)

5.4 Discussion
5.4.1 Results discussion
The study indicated that drivers have different perceived needs and wants in different driving contexts. However, when analysing the grading in order to create the CAT, it was also important to look at the open ended comments and the level of consensus and not only at the average.

As indicated by high standard deviation and many open end answers for some functions, there seems to be a difference in opinion about what or who should provide the information. Should it be the car, the road authority or the driver? This is an important factor, of course, and a more thorough analysis about who is the actor is needed for some of the functions.
It was furthermore indicated that it is also important to have consensus about the contexts. For instance, the subjects used different strategies when they graded functions, such as "average between the two" or "a five if before", which indicates that the context is "weak" or inconsistent", which may cause errors. As a consequence, the context should be re-evaluated.

The result may be used for an optimization of display space. For instance, "show speed" has a difference in mean value of 2.0 between being in a parking place (3.0) in comparison with driving on the highway (5.0) while "show view near behind the car" has 1.7 in difference between highway (4.2) and the parking place (2.5). It would therefore be possible to exchange functions instead of adding information. Whether this particular example is a good idea or not is not apparent.

The grades could also be used as a weight when evaluating future systems regardless of whether they are adaptive or not. For instance, a design layout could be evaluated for a specific context such as an intersection.

5.4.2 Methodological considerations

Choice of method

The study contains several independent methods. The reason for this is that there are no known methodologies that consider all the necessary issues.

Participants/Subjects

In general, when making a Cognitive Work Analysis, the designer of the system has to move outside the user community to get input for the design (Burns & Hajdukevicz, 2004). The idea is to provide the user with a greater level of support than if the data collected came from users solely through, for instance, surveys, as in a User Centred Design (UCD) approach.

In this study the engineers defined the different functions and the safety people and HMI experts defined the different contexts. However, for historical reasons, tradition, or because the driver likes to have information or to feel in control, it is necessary to also consider that reasons other than rational ones can influence the choice of functions. Cars are consumer products, and it is therefore also important to understand what the users want. Therefore, real users were recruited from the personal network of the research team and not only researchers or engineers.

Simulation interview

To make test subjects better decision makers, there was a need to support the subject in identifying important attributes, such as safety or environmental friendliness (Wickens and Hollands, 1999). 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, in order to make the grading of the function better.
Driving context
There are of course more possible contexts than the few chosen and, depending on the
use of the results, other contexts could have been included. For instance, if the
purpose was to drive more fuel efficiently, contexts such as hills, slopes, approaching
an intersection and so on would have been established.

This study’s contexts were decided by HMI and safety experts, resulting in contexts
that are more important from a safety perspective. However, the study has a between-
subject design, which makes it possible to add other contexts later. For instance, input
from power train engineers could provide ways to reduce fuel consumption.

Apparatus
There were three reasons for showing pictures, and for showing them simultaneously.
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.
Secondly, this was done to avoid serial position effects (see for instance Wickens and
Hollands, 1999) that may occur if the contexts are presented in sequence. Third, the
pace at which a driving task is performed may be different from the subject’s own if
the subject is presented with, for instance, a movie.

There are indications that presenting the contexts on a board worked as intended. The
subjects browsed the board and did not seem to favour any of the pictures. They
discussed the whole sequence of the context, mentioned events from their own
experiences that could be applied to the pictures and discussed their own pace in
similar situations.

Function
Usually when creating a CAT, the abstraction is on the general function level (the
middle level in the WDA decomposition). However, this level seemed to be too
abstract for the users to understand. Moreover it is also challenging to illustrate the
function to reduce bias from well known functions, which may be done by making the
physical object more abstract. Or, to be more specific, by showing what the function is
doing rather than what it is.

The trade-off between being too abstract to be understood, reducing bias of well
known systems, and how the CAT is intended to be created, was to choose the
abstraction level, the physical function.

Using the 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 subjects gave the
impression of thinking twice before giving their grade. Nevertheless, a comparison
between the two ways of presenting the functions would be appropriate.
Grading
A scale from 1-5 (1= not important, 5= very important) would not have worked since a function could be worse than "not important". A function could also be not applicable, inappropriate or dangerous. For this reason a waste bin was added to the scale.

Difference between need and perceived need
In the study the drivers decided what information they perceived to be needed or wanted in a specific context. It could be argued that drivers do not know what is needed for a specific context. However, it is the designer that is responsible for also adding knowledge about, for instance, incident data, human models and decision making.

5.4.3 Statistical analysis
To keep the time spent on each interview within reasonable limits, and to be able to add contexts afterwards, the subjects were interviewed in only one or two contexts (between-subjects design). There may be research limitations in the statistical analysis as a result of this.
Furthermore, the number of respondents was limited to ten persons in each context and, as a consequence of the waste bin, the size of the population varied in almost every function, which made it even more difficult to calculate different statistical measures. This of course poses limitations when comparing the contexts. On the other hand, the grading and the open ended answers may together give a qualitative answer about if and how well a function suits a particular context.

A reliability check was also made by judging whether the subjects were able to give a similar grade if the questions were repeated. The function "show average speed" was duplicated and the small difference between the individual grading and the mean values indicates that the respondents reasoned in much the same way.

However, to validate the methodology further, it is still recommended that at least one context category be repeated with a greater number of subjects.

5.4.4 Generalization
There is a large difference in driving between for instance in Sweden and China (Lindgren et al., 2009); not only in the sense that the contexts are completely different but also that the driving culture is different. It is therefore likely that the results are not representative for all markets.
6 How can the negative aspects of adaptivity be avoided by design? (Paper C)

6.1 Introduction
Research question four was: “How can the negative aspects of adaptivity be avoided by design?”

Adaptivity or automation is yet not very common in cars. Problems with driving automation such as over-trust or complacency, under-trust and mode errors are likely to appear in highly automated environments, as described by for instance Stanton and Young (2000).

However, little has been written about how to solve the potential problems. A natural way to find more information was therefore to search in a field where automation has been going on for a longer time, namely the process and power industry. A recent approach to avoiding automation induced errors was to make the agents within the system become team players.

Team players agree on a common ground, they show their intention; they show reasoning, express their limits of performance and so on (See Figure 10 or 14). The approach has so far primarily been used in the process or power industry.

How can the knowledge from one field be transferred to another? System designers and human factors experts in the vehicle industry are those who know most about the automation of vehicles. Therefore, an expert evaluation was made of how to apply the team player approach to car design.

6.2 Method
Two female and eight male experts at Volvo Car Corporation, Luleå University of Technology and Chalmers University of Technology participated in the study. The areas of expertise were design of Active Safety systems, design of Driver Information Systems and HMI design.
1. The experts were first sent an e-mail with a scenario and called to an interview.
a. The subjects were told that the interview was anonymous and hence the participants were asked not to tell others about the interview.
b. The scenario was described as follows: "It is morning and you have just left your 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 with fuel and doesn't need 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 efficiently you drove last time and you are reminded to change gear earlier. You start the engine. The screen now shows a 360 degree 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 in size. There is also advice that you should be careful about meeting traffic when turning left since many accidents have happened...".
c. The experts were also provided a list and a description of potential problems by automating information flow. The problems described were over-trust, under-trust, skill degeneration and workload when automation fails.

2. Two weeks after the call, the participants were interviewed individually.
a. The participants were confronted with the ideas of making agents into team players. The ideas were presented one at a time.
b. Each of the attributes of being a team player was discussed in a car automation context (See figure 14). Notes were taken.

<table>
<thead>
<tr>
<th>Before:</th>
<th>Share common goals, Show intention, Share representation of the problem state, Directable, Negotiable, Being observable, Observe humans, Negotiable levels of authority, Future oriented</th>
</tr>
</thead>
<tbody>
<tr>
<td>During action:</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>After:</td>
<td>Explain why action, Feedback, Why did it do this? Observability (including things being observed, observer, context), Change behaviour after negotiation, Give humans feedback.</td>
</tr>
</tbody>
</table>

Figure 14. Behaviour as a team player

c. After having discussed the different team player attributes the expert was then told the judgment of the previous experts and could re-evaluate his/her own judgment.
d. Notes were again taken.

3. The results were summarized by the author.
4. The results of the interviews were discussed in a focus group.

6.3 Results
The experts found the team play approach both challenging and interesting but found a 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 become team players than as being team players. What is needed is "team building"; the solution suggested is a compromise and could be described and summarized as a separate view for the above mentioned information.

6.4 Discussion

6.4.1 Results discussion
An important difference between the process or power industry and transportation was clearly indicated in the study. The difference in visual task demand is large, which made the team player approach difficult to implement.

6.4.2 Methodological considerations

Choice of method
Focus group discussions were considered since it is a time efficient and very straightforward method. However, bias from strong members, such as leaders and seniors, was expected and would have given a result that does not represent the whole group. Instead, the Delphi procedure was used to reduce bias (Kirwan and Ainsworth, 1992).

Number of participants
The reason for having so many experts was that they were experts in automated systems of cars, but in different areas, which may cause disparate answers.

Second feedback loop exchanged by focus group
The second individual feedback loop was exchanged with a focus group. The reason for this was that the complexity of the interview results was too large to be handled by the experts, again due to time constraints. This may have added bias. However, it seems that the trade-off between time used and bias stayed at a very good level.

Having a focus group at the end of the study instead of the feedback loop also made a statistical analysis impossible. If the experts had instead gotten the information fed back individually and anonymously it would have been possible to obtain unbiased statistical data. However, the focus was to get ideas about how to make agents into team players, and the interviews gave more than expected. Furthermore, it may be better to develop the ideas and then get acceptance data from the team.
7 Conclusions
The main objective of this thesis was to investigate if adaptive driver information has a potential to improve driver performance in fulfilling different purposes of driving, improving SA and optimizing workload.

The answer to the four research questions and a discussion of each of them are presented below.

RQ 1. What are the purposes of future driver information and their relations to different functions?
The different purposes of driver information have been identified using the framework of Work Domain analysis. The purposes have then been linked together with the different existing and future functions in the car in order to find strong and weak relations or, to be more specific, areas of improvement.

Driver information has to be more than just showing the car’s status, as is done today. The purpose of future driver information must also be to support safe, environmentally friendly, efficient, legal and enjoyable transportation. Today’s driver information is indirect and needs to be interpreted to be useful to the driver. There is therefore also a potential in supporting knowledge based behaviour and strategic decision-making.

RQ 2. What are the potential benefits and negative effects of adaptive driver information?
Adaptive driver information seems to have a potential in supporting the driver. However, adaptivity is multi-dimensional and, so far, the potentials and the main problems have been identified. The different input factors for SA and the potential automation problems are identified, but how great an impact each of them should have on the adaptivity remains to be determined.

RQ 3. What information do drivers need and want throughout the driving task?
It has been shown that different information is perceived as needed or wanted in different contexts but that there are big differences among drivers in some of the functions. The results could be used as a guideline for the design of future driving information. For instance, functions that are perceived as being less important may be
made less salient and those that are more important may be made more salient in different contexts.

**RQ 4. How can the negative aspects of adaptivity be avoided by design?**

From the frame of reference (chapter 3) it can be assumed that the main negative effects of adaptive driver information have been identified and could be classified as automation induced problems. Some suggestions for how to manage the different drawbacks have been presented and one of them, the team player approach, has been looked into more deeply. It seems that there is a potential in the team player approach if a reduction of the visual demands can be achieved.

It therefore, seems that adaptive driver information has a potential to improve driver performance, support goals of driving, improve situation awareness and optimize workload and there are accessible solutions for the problems that are related to adaptivity.

The field of driver information seems to be quite conservative and there is thus a great potential for innovations. During the research, three patents have been developed: a new type of speedometer, a safety gauge and a situation awareness gauge. These can not be presented here for intellectual property reasons.
8 Further work

One research question (RQ3) was to identify what drivers want and need depending on different input factors. In this thesis, only the context has been looked into and driver state, historical behavioural data and so on have not yet been investigated. Further research needs to establish which are the most influential of the input factors in improving situation awareness.

The results reported in paper B indicate that there is a large difference between people, pointing at a need to investigate the variation between individuals. The data from paper B should, furthermore, be complemented to make a more thorough statistical analysis possible.

One of the next steps in the project is to suggest design guidelines to support drivers throughout the whole driving task, including planning and feedback. EID is used to support the knowledge of the different constraints throughout driving. A suggestion for how a constraints based interface could look like will therefore be developed.

Methods have been developed to evaluate SA, but these are mainly for aviation. A method for how to evaluate SA for car driving will therefore also be developed. The idea behind the method is to combine the results of EID with a more user centred design approach. In brief, the general function level of driver information (developed in WDA) is graded by real users. The results influence the salience and appearance of a general function at a specific moment. The complete design could thereafter be evaluated by how well the different general functions were perceived, with the grade as a weight, by real users.

Another issue to look into is that driver performance is reduced during long periods of low workload. It seems reasonable that introduction of workload can improve performance by for instance preparing for a high peak in workload. A hypothesis to be analysed is whether a move of workload in time can improve driver performance (see figure 15).
Figure 15. Illustration of how performance level may possibly be increased by information/priming. The dotted line represents if workload has been induced to the driver.
References


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. Rasmussen (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 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.

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 FPs' 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 Functional Purpose (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 snowflake. 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.

***

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 the speedometer. The Energy of the car is the kinetic energy (i.e. avoid roads with bad accident statistics).

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 ACC. 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.

***

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.

***

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 occurs. 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 efficient. In most navigation systems it is possible to select 'Fastest Route'. Traffic Message Channel (TMC) and in e.g. the USA Radios AM Band provides information about traffic accidents or congestions. This makes it possible to avoid obstacles that may increase time on the road.

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.

***
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.

***
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 traffic lights ahead might also give the driver a better chance to distribute the vehicles speed more evenly. Most navigation systems in today's cars provide the possibility to change between fastest and shortest route. Why not introduce the greenest route? Finally, design the tachometer or provide other gear change advisor to support correct gear change.

***
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 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 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.

REFERENCES

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APPENDIX 1.


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
Paper B

Driver Information in different contexts

"Or, what do who need and want when?"

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Abstract: Driving a car is a complex task and requires that the driver has appropriate information for different contexts when driving. The functional growth of driver information is expected to continue due to technological push and drivers’ needs and desires. Increased driver Situation Awareness is expected to improve drivers’ performance. One way to provide Situation Awareness is to present context relevant information from the vehicle.

The aim of this study was therefore to investigate what information people perceive needed and wanted from the car in different contexts and to what extent there is a consensus about the function. 33 private car drivers were interviewed and asked to grade a number of possible functions in a car in different contexts. The results indicated that people need and want different types of information in different contexts. It is furthermore indicated that there sometimes is 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.

Keywords: Adaptive, Context, Driver information

1. Objectives
An increased awareness about safety, the effects of carbon footprint and a denser traffic situation are contributors to a change in the need of driver information. Now and in the near future it is expected that DI will have an extended, more complete, purpose, which is to support safe, environment friendly, efficient (cost and time), legal and enjoyable (comfort, feel of control, fun etc.) transportation (Davidsson, 2009).

The last of the five purposes, "enjoyable", expresses that some of the functions in the vehicle must exist just because drivers may perceive a need or want or desire them. They may find the function not needed but "enjoyable", "fun" or "it is tradition". If a function that is perceived needed or wanted are deleted from the function list because it is not needed from an expert point of view the manufacturer may be less popular.

Drivers’ real needs may be described by Michon's (1985) taxonomy about strategic, tactical and operational levels of control or other driver models by for instance Rasmussen (1985), Ranney (1984).
Transportation can be regarded as a complex and dynamic system in which the driver needs to be aware of every situation. Situation Awareness (SA) is the engine that drives the train for decision making and performance in complex dynamic systems (Endsley, 2003). SA breaks down into three separate levels: Perception of the elements in the environment, comprehension of the current situation and projection of future status. Even though the concept has been widely criticized (e.g. Flach 1995) it contains several useful ideas. For instance that people make projections of future events based on their actual mental model of the situation, act instead of react and select to perceive which indicates that motivation is involved (Vogel, 2002).

One possible way to improve drivers' performance could therefore be to improve SA and Alfredson (2007) concludes that, if we learn how to manage differences in SA in the development of complex systems, the value of the systems in use will increase. Alfredsson (2007) also suggests that an 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.

But, are there visual, manual and cognitive resources left for functional growth? If future driver information is implemented in a careless way, the systems may have a reduced potential to support their purposes. An even worse scenario could be that the systems make driving less safe, less environment friendly and so on, through visual, manual or cognitive distraction.

Showing all the information simultaneously would probably create visual clutter and inattention. One solution for reducing clutter is to only show the information needed or wanted for a specific driving context. Other input factors than context could of course also affect information content but this is not investigated in this study.

A natural and basic starting point is therefore to study how context govern driver information functions. Another issue is of course the level of consensus among drivers about what information should be available when. For instance, does everybody agree that the speedometer is useless while the car is parked?

The purpose of this study was therefore to investigate:
- If drivers want or have a perceived need for different functions in different contexts.
- What information different drivers perceive needed and wanted in different contexts.
- To what extent there is consensus about each function.
- And to illustrate the activity in the different contexts.

2. Method

2.1. Approach

This study is mainly qualitative and the numerical data used is not meant to prove anything, solely. The reason for this is that when working with future functionality an understanding of how people think is necessary, rather than only study what they have or do
today. The numerical data should, instead, together with the interview form an answer to the research questions.

2.2. Subjects and participants

33 Swedish private car drivers, 14 men and 19 women, participated. The subjects were on average 42 years old; the minimum age was 20 and maximum age 69. The drivers’ experience spanned between beginners to experienced drivers 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 Activity Template (CAT) (See appendix 1).

2.3. Driving contexts

The following contexts were established:

- Before going to-entering the car/post driving (BEF).
- Car parking (when parked, in a car park or in a garage, looking for a parking place) (CPS).
- City crossing (intersection, traffic light, left turn across path, straight crossing path, roundabout) (CC).
- Highway crossings (intersection, red light, left turn across path, straight crossing path, roundabout) (HC).
- Straight highway driving (negotiating a curve, drifting, lane change merge) (SHD).
- Driving in a queue (Q).

2.4. Apparatus

Nine pictures (3x3 matrix) illustrating one context group (a context group is different roads but a similar road type) were displayed on a paperboard. 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 bird’s eye view. See figure 1. The contexts "queue" and "before/after" driving are difficult to illustrate by pictures. Instead, written text was used.

Figure 2. Apparatus to present scenarios and to grade functions (straight highway driving)
2.5. **Simulation interview**

A simulation interview was conducted, inspired by the Applied Cognitive Task Analysis (ACTA) method (Militello & Hutton, 1998). The simulation interview is a walkthrough, a mental simulation, of driving in or through the specific context and then the participants is asked to think of what they do, how they do it, what they find difficult and what their feelings are.

2.6. **Functions**

Davidsson et al. (2009) previously 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. The 70 physical functions can be seen in the CAT in Appendix 1.

2.7. **Scope**

Most of the participants were interviewed in two contexts but some in only one. There were ten subjects in each of the six contexts, which gave a total of 60 interviews. Each interview lasted, in general, between half an hour and one hour.

2.8. **Grading**

The design of the grading scale was a scale from 1-5. (1= Not Important, 5= Very important) and a waste bin.

2.9. **Illustrating the functions in the different contexts**

One way to arrange the different functions in the different contexts is to use the contextual activity template (CAT) which was introduced by Naikar et al. (2005). CAT is included in the second level in Cognitive Work Analysis (CWA) (See for instance Vivente, 1999) which is called Activity Analysis. In the contextual activity template was each function at the physical function level (PF), scored for its importance for a specific context.

![Figure 1. Contextual Activity Template (CAT) (Naikar et al., 2005)](image-url)
2.10. Procedure. (1-4 is the simulation interview)

1. The subject sat down in front of the board with pictures.
2. The subjects were given instructions:
   a. Look at the pictures on the board (see Figure 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 in phases going from the red to the green dot (provided on the pictures).
   f. Think of your emotions in this kind of context.
3. The subjects were left alone for five minutes.
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 mention 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 subjects were asked to "grade the function between 1-5 were 5 is very important and 1 is not important or if the function is not applicable, inappropriate or dangerous for the context, put it in the waste bin".
   b. The subject 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 subject took a card on which the physical function was printed from a randomly mixed stack of cards. The subject read the physical function and the number (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 Figure 1).
   d. If the subject put a comment, notes were taken.
   e. The subjects were then showed gratitude for their participation.
6. A CAT was created from the grades and the open end answers by the research team.

3. Results

3.1. Does drivers want or have a perceived need for different functions in different contexts?

It is rather intuitive and the result also indicates that drivers want or need different functions in different contexts. One way of finding out if drivers want or need different functions in different contexts is to follow the function through the different contexts, for instance, the function "Show where the roads are heading in the next intersection".

Before and after driving, this information is of little use to the driver. The mean was 1.8, and 60% found it inappropriate or not applicable. Then, when in the car park or in the garage, the drivers started to prepare for departing. Some found the information interesting, but most believed that it was of no help. The mean was 2.5, and 50% found it inappropriate or not applicable. At the highway crossing the ranking of 4.4 and standard deviation of 0.5 indicates both that drivers wanted and/or needed the information and that there was consensus about it.
However, one driver found the information useless and threw it in the waste bin. At the straight highway, the driver again found the information less important. If the driver ended up in a queue, the grading increased again. The grade of 4.0 indicates that there is a need for this type of information. From the notes taken, it is understood that the driver wants to solve the queue problem by finding another way to the destination. At the city crossing, drivers again found this information useful, as in the case of the highway crossing.

The average of the grades for all contexts for this particular function is 3.6. This reveals 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.

This is one example but the way of analysing a function is the same for all functions.

3.2. Which information do different drivers need and want in different contexts?

3.2.1. Grading of physical functions

Because of the large number of functions (70), Figure 2 shows only a selection of the grades from the grading exercise. The complete table of results can be acquired from the author upon request.

![Figure 3](Image)

**Figure 3** Selected grades from the drivers’ grading of functions in different contexts. (* = No standard deviation, only one or less than one subject graded the function.)

3.2.2. What do drivers need and want when and to what extent there is consensus about each function?

The results from the different contexts are shown in the following section and in the context activity template (CAT) (See Picture 2 and the appendix 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” are graded high.

However, the consensus is low for many of the functions. For instance, "show recommended speed due to road conditions" was graded 4.2, although three out of ten subjects stated that they did not want the function at all.

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 of course is of less use in this context.

Car parking

While 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 represented among the top grades. These functions could be considered tactical and/or operational. There is consensus about the first two functions mentioned above. However, the latter show 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 ended up 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.

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", "show 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 subjects about which information is useful and wanted.

"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 while driving in intersections.

Straight highway driving

The functions are mainly strategic or tactical. "Show speed”, the often largest gauge, finally got the highest grade. Moreover, 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 case of queues or accidents)” and "show
recommended speed due to road conditions, visibility etc." were also given a high grade. There is high consensus among the drivers that these functions are important.

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 in these functions was rather high.

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 to solve the problem themselves.

Interestingly, functions such as "ability to play game", "ability to surf on the Internet" or "ability to watch a movie" were rated rather high. However, there was a high variance, which indicates low consensus.

The functions that were graded lowest are mainly related to speed, which give information about something that the driver in fact lacks. These were functions such as "warn if the car enters a curve at too high a speed", "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 ended up in 24th place.

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 were given 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".

Notes
Notes were taken during the grading. These notes help to explain why the subjects gave the grade they did and the source of the information, car, driver or 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 subject prefers a sign instead of in-vehicle information)
• Show information about dangerous roads / Straight highway driving: "Want to see in reality" (indicates that the subject prefers to see for him/herself rather than using in-car information.)

3.2.3. CAT

The CAT is an interpretation of the grading, the waste bin and the open end answers for each function made by the research team. The bars in the CAT shows were a function "typically should be" and the dotted line where it "can be".

4. Discussion

4.1. Result discussion

The purpose of this study was to investigate what information different drivers perceive needed and wanted in different contexts.

4.1.1. If drivers want or need different functions in different contexts.

The study gave, by the grading and the open end answers, an indication about that driver have different perceived needs and wants in different driving contexts. Even more traditional functions such as "show speed" showed great differences in how they were graded in the different contexts.

4.1.2. What information different drivers perceived needed and wanted in different contexts.

A CAT was created to easily illustrate the information needed in different contexts. The CAT can easily be used to design a new interface for, for instance, queue-driving which is rather common in urban areas. Here an explanation of the reason for the queue, a way to solve the problem by for instance re-routing is important meanwhile speed is of less importance. Drivers also want to be able to reduce the effects of queuing by for instance visual entertainment.

4.1.3. To what extent is there a consensus about each function?

It is indicated that there are differences between different persons’ opinions about what or who should provide the information. 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. Others liked "systems" for almost everything.

One example is in "help to recognize other nearby vehicles" in a highway crossing. The comments pointed in this direction and it received a high grade (4.0), a high variance (1.2) and two subjects put the function in the waste bin. It is likely that this function may help some and annoy others, and this must be considered in the design process.

It is also important with consensus about the contexts. For instance, the information wanted and needed before driving and after driving is sometimes completely different. This made it difficult for the subjects to give a grade that was equal for both before and after. Consequently, the subjects used different strategies when they graded functions, such as "average between the two" or "a five if before". However, this indicates that the context is "weak" and can also be seen as a useful answer.
4.1.4. Usefulness of the results

- The result could be used as a guideline for design of future driving information. For instance, may functions that are perceived less important be made less salient and more important more salient in different contexts.
- The result could be used for optimization of display space. It may be possible to instead of adding information exchange functions.
- The grades could be used as a weight when evaluating future systems.
- When deciding whether a function should be activated automatically or manually, the system designer may look at the standard deviation. A large standard deviation may indicate low consensus about the function and, consequently, some of the drivers may be surprised or annoyed by receiving this information automatically.

4.2. Methodological considerations

4.2.1. Data Collection

Normally, when performing a Cognitive Work Analysis, the designer of the system has to move outside the user community to get input for their design (Burns & Hajdukevicz, 2004). The idea is to provide the user with a greater level of support than if the data collected came from users solely via for instance surveys, as in a User Centred Design (UCD) approach. In this study the engineers defined the different functions and the safety people and HMI-experts defined the different contexts but real users were used to grade and put comments.

4.2.2. Subjects

The main idea behind this study was that real users may have more than rational reasons, _wants or desires_, for ranking a function high or low, while experts perhaps are better at judging _needs_. This dimension needs to be considered since private cars are consumer products and purchase involves emotions that not always are rational. Therefore were real users recruited from the personal network of the research team and not only experts.

4.2.3. Simulation interview

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

4.2.4. Need and want

It could be argued that drivers don't know what is needed for a specific context. However, it is the designer that is responsible for also adding knowledge about for instance incident data, human models and decision making.

4.2.5. Driving context

There are of course more possible contexts than the few chosen and depending on the use of the result, other contexts could have been included. This study's contexts were decided by HMI and safety experts why the contexts are more important from a safety perspective. However, the study has a between subject design which makes it is possible to later add other contexts.
4.2.6. Apparatus

The reason for showing pictures, and showing them simultaneously, was 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. Secondly, to avoid serial position effects (e.g. Wickens, 1992) that may occur if the contexts are presented in sequence. Third, the pace at which a driving task is performed may be important. If the subject is presented a movie where someone else is driving, the pace could be different from the subject’s own, and this may well affect the result.

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

4.2.7. Function

Usually, 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 be understood.

Another important challenge was how to illustrate the contexts in order to reduce bias from well known functions. A way to make the less used functions a chance was needed. By shifting the representation from low, detailed level to a higher level of abstraction with less resolution makes complexity look simpler. Metaphorically, moving up one or two levels allows drivers to “see the forest for the trees” (Vicente, 1999).

The trade off between being too abstract to be understood, bias of well known systems and how the framework use to be performed was to chose the abstraction level, physical function.

Using the abstract level of physical function rather than physical form or general function also seemed to have work as intended, but it is difficult to see how well. One indicator was that, instead of just grading the function without much thought, the subjects gave the impression of thinking twice before giving their grade.

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

4.2.8. Statistical analysis

There may be research limitations in the statistical analysis. To keep the time spent on each interview within reasonable limits, and to be able to add contexts the subjects were interviewed in only one or two contexts (between subjects design) which of course poses limitations when comparing the contexts.

4.2.9. Grading

A scale from 1-5 (1= not important, 5= very important) would not have worked since a function could be worse than “not important”. A function could also be not applicable, inappropriate or dangerous and for this reason a waste bin was added. For instance, “Show speed” may be considered not applicable before driving and after driving, “Ability to surf on the internet” may be inappropriate and dangerous while driving in an intersection.

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

4.2.10. Reliability

To judge whether the subjects would be able to give a similar grade if the question were repeated, ”show average speed” was duplicated (functions 14 and 77, see figure 4). 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 (underline) subject had a greater difference than one 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 subjects.

It is likely that the results are not representative for all markets. There is a large difference in driving between for instance Sweden and China (Lindgren et al., 2008).

5. Conclusions

The study indicates that drivers want or have a perceived need for different functions in different contexts and even very common function vary in importance between different contexts.

A zoom function can illustrate what information different drivers perceive needed and wanted in different contexts. These were illustrated in a Context Activity template that shows the importance of a function in a specific context.

The standard deviation in the grading together with the open end answers gave an indication of to what extent there is consensus about each function. There is a big difference among drivers for some of the functions which point at a need for individual adaptation of some functions.
References


Paper C

Applying the "Team player" Approach on Car Design

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Professor Håkan Alm
Luleå University of Technology, Luleå, Sweden

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>Table 1. Behavior as a team player</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before:</strong></td>
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<tr>
<td><strong>During action:</strong></td>
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<tr>
<td><strong>After:</strong></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 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 1. Summary of interview results.

<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>
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<tr>
<th>2 B. Show intention, Future oriented</th>
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<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>

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<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>
2 E. Share representation of the problem state,

- Fear too much dialogue.
- 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
prioritization”).
- 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 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.

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.
- History over ordinary happenings after driving (Briefing).

**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
