UPTEC STS08 015
Examensarbete 30 hp
Mars 2008

Design of a driver-vehicle interface for local surrounding world information in intersections

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Abstract

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In Europe 40 000 people get killed and 1.7 million get injured in traffic accidents every year. Of all accidents reported, urban intersection accidents are over represented. Autoliv, Volvo Car Corporation and Chalmers University of technology are working together to reduce the amount of intersection accidents and near-to-accident conflicts between vehicles and other vehicles, pedestrians or bicyclists. In addition to developing technical components, a challenge is how to design an effective driver-vehicle interface, which meets human capabilities and limitations.

Through a user centred approach the first concepts of a driver-vehicle interface for an intersection support and warning system was developed and evaluated. The thesis discusses the system output to support drivers negotiating an intersection safely. It also addresses how this output should be presented in regard to existing guidelines and users' opinions.

The thesis shows that warnings about other road users are perceived as being the most important and helpful output. Both results from crash data analysis and design evaluation with future users indicate that drivers would also accept and benefit from a support system. This system should be giving information about an upcoming intersection and also information to notify the driver about other road users. A head-up display was by far the most appreciated location for such information. Further development of the interface design and evaluation under real-world conditions need however to be done.

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ISSN: 1650-8319, UPTEC STS08 015

Populärvetenskaplig beskrivning

I Europa omkommer ungefär 40 000 personer varje år i trafiken och miljontals skadas. Den mest kritiska punkten i vägnätet, där flest olyckor sker, är korsningar. Här måste en bilförare vara uppmärksam på flera olika områden och faktorer, till exempel fotgängare, cyklister, andra bilister och trafikregler. Dessutom måste föraren vara beredd på att snabbt reagera på oväntade händelser. Utvecklandet av en ny teknik i samarbete mellan Autoliv, Volvo Car Corporation och Chalmers tekniska högskola förväntas kunna öka säkerheten i korsningar och därmed minska antalet olyckor. Målet är att kunna stödja en bilförare genom att ge information i bilen så att denna/denne på ett säkert sätt kan köra igenom en korsning. Förutom att utveckla de tekniska komponenterna är det en utmaning att designa ett effektivt användargränssnitt som stödjer människors förmågor och begränsningar.

Detta examensarbete syftar till att utveckla och utvärdera ett förslag på interaktionen mellan en förare och ett support och varningssystem för lokal omvärldsinformation i korsningar. Genom att använda en användarcentrerad designprocess har följande frågor kunnat besvaras: vilken information ska visas för föraren för att kunna öka säkerheten i korsningar, vilken är den lämpligaste placeringen av informationen och hur kan informationen presenteras/designas? Examensarbetet har tagit hänsyn till existerande riktlinjer för informationssystem i fordon, såväl som bilisters egna åsikter.

Studien visar att varningar för andra trafikanter upplevs vara den viktigaste informationen att visa för föraren. För att kunna förebygga att kritiska situationer överhuvudtaget uppkommer har olycksanalyser, intervjuer och utvärderingar även visat att förare skulle acceptera och kunna dra fördel av att få information om omvärlden i ett tidigare skede. Denna support skulle då innehålla information om en kommande korsnings egenskaper och även information om befintliga trafikanter i korsningen, såväl andra bilister som fotgängare och cyklister. Vidare har studien visat att informationen helst ska presenteras för föraren på vindrutan, i förarens synlinje. Ytterligare utveckling av designen och utvärderingar, exempelvis i en simulator, måste dock göras.

Preface

This master thesis has been written as a part of the studies at a program named Sociotechnical Systems Engineering at Uppsala University. The work has been carried out at the Research and Development department at Volvo Car Corporation in Gothenburg.

I would like to thank everyone that has helped and inspired me during this thesis work, including my respondents and the personnel at Volvo Car Corporation. Special thanks goes to my supervisors Niklas Adolfsson and Johannes Agardh for being very supportive and helpful. Furthermore, I would like to thank my supervisor at Uppsala University, Anders Jansson.

I would also like to show my gratitude to Azra Habibovic for tips about interesting seminaries and reports. For their thoughts and exchange of ideas a huge tanks goes to Pia Mämmioja, Gabriel Larsson and Michael Bodin, who has written their master's thesis during the same period of time.

Gothenburg, March 2008

Caroline Hägglund

Table of contents

1 Introduction

Traffic is an interaction between roads, vehicles and road users. Accidents occur as a result of a failed interaction. ”He came out of nowhere, I didn’t see him!” – is a frequent comment among drivers who have been involved, or almost involved, in traffic accidents. In reality it often means that the driver lost his/her focus on the world outside the car for a moment. In Europe 40 000 people get killed and 1.7 million get injured in traffic accidents every year. Road casualties in the EU cost 1.5 billion Euros per year. Increasing traffic security could therefore gain huge human and socio-economic benefits. (SVEA/SAFER, 2007)

Of all accidents reported, urban intersection accidents are over represented (Rössler et al., 2005). Intersections are critical points in the roadway system where traffic movements are most frequently in conflict with each other. Drivers have to scan several different areas and keep track of several different elements, such as pedestrians, bicyclists, vehicles and traffic devices. This to get the information needed to pass safely. Intersections also require drivers to make responses on emerging conditions under time pressure. If drivers cannot meet all demands present, conflicts with other road users increase. (Richard, Campbell, Brown, 2006) In urban environments, geometry of surroundings can be especially complex, including elements of infrastructure (for example bus shelters) and buildings that may mask obstacles. Intersections are thus a location where drivers are in need of safety improvements. (Rössler et al., 2005)

1.1 Technology development for intersection safety

Motor vehicle industries and safety research programs all over the world have initiated a new safety technology development for intersection safety. Autoliv, Volvo Car Corporation (VCC) and Chalmers University of technology are for example working together to create a new proactive safety solution that supports the driver when approaching an intersection. The goal is to reduce the amount of accidents and near-to-accident conflicts between vehicles and other vehicles, pedestrians or bicyclists. This will be done by supporting the driver with enhanced and augmented information about important intersection objects. Furthermore, warnings in critical situations will get the driver to brake or steer away from the hazard. (Volvo Car Corporation, 2006)

Today different car-car crash warning systems already exist. They are designed to sense an impending collision and alert the driver. These systems are collecting information using an in-vehicle sensor based system. Current sensor technologies have however a limited visibility. They cannot see behind obstacles and there are also limitations in the view of lateral and longitudinal areas. (Meinken, Montanari, Fowkes, Mousadakou, 2007) Autoliv’s, VCCs and Chalmers’ goal is therefore to create an intelligent intersection with sensors that can collect more information than an in-vehicle system. The intersection sensors will be able to communicate information to the vehicle on a circa 200 meter distance. The vehicle will evaluate the information together with applicable vehicle status, for example turn indicator status. Applicable information will then be communicated to the driver via a driver-vehicle interface. (Volvo Car Corporation, 2006)

In addition to developing technical components, a challenge is how to design an effective driver-vehicle interface, which meets human capabilities and limitations in the safety critical situation that appears in an intersection. The system should be assisting in problematic situations and contribute to an improved driving behaviour. It must not pose an extra workload or distract the driver's attention from the driving task or the surrounding traffic.

1.2 Purpose & question formulation

This thesis intends to develop and evaluate the first concepts of a driver-vehicle interface for an intersection support and warning system.

To be able to fulfil the purpose, the following questions will be addressed:

- What information should be enhanced to the drivers to support them in negotiating an intersection safely?
- Where should the information be presented not to disturb the driver from focusing on the road and traffic?
- How should the information be featured?

1.3 Delimitations

Focus is set on the interaction between the system and the driver. This thesis does therefore not look into the technical aspects of the solution and the development of the technical components is still in early progress. An assumption, that it is possible to build sensors that can collect relevant local surrounding world information in intersections, has therefore been made. Difficulties in creating a reliable intelligent intersection have however partly been taken into consideration.

The mathematical aspects on how to determine a dangerous situation and the risk level for a collision have also been excluded. Even though timing is critical to a system's usefulness, exactly determining message timing is also beyond the scope of this thesis. Important factors to consider have however been identified during the thesis work.

Volvo cars are sold to about 100 countries all over the world. (Volvo Cars, 2007a) A support and warning system is supposed to be used and understandable for all Volvo drivers. In this thesis though, only Swedish drivers have had the opportunity to evaluate the design. Furthermore the concepts should not be seen as design suggestions for all possible situations, but are tightly connected to the intersection scenario described in chapter 6.1 and appendix B.

1.4 List of acronyms

CCW	Cautionary Crash Warning. A warning that requires attention and provides a preparatory warning cue to the driver that an emergency response may be necessary.
HUD	Head-Up Display. Information is reflected on the windscreen in the driver's line of sight.
ICW	Imminent Crash Warning. A warning that requires an immediate corrective action.
IDIS	Intelligent Driver Information System. A workload manager that adapts the in-vehicle information according to the driver status and driver conditions.
LED	Light-emitting diode ramp. Red light is reflected on the windscreen.
VRU	Vulnerable Road User. A person that is extremely vulnerable, e.g. pedestrian or cyclist. Usually it also includes motorcyclists, but they have not been taken under consideration in this thesis.

1.5 Disposition

The first section of this thesis consists of the theoretical frame of reference, including theory for a human centred design process and design guidelines for in-vehicle information systems. Chapter 3 describes the working procedure of the thesis and results are given in the following four chapters. Chapter 4 presents the constraints on the design space from a driver's physical surrounding. It also highlights information that may be critical for drivers to perceive to be able to pass an intersection safely. Chapter 5 starts with a specification of requirements important to gain system usability and driver safety. It ends with indications of drivers' requests on an intersection support system. In chapter 6 the developed concepts are described and results from an evaluation of them are presented in chapter 7. Chapter 8 finally reflects over the results from the thesis work and consists of a discussion and recommendations for future research.

2 Theoretical frame of reference

This chapter presents the theoretical reference frame used when planning, making decisions and realising the work needed to fulfil the purpose of the thesis. It includes a description of a human centred design process as well as a review of existing guidelines and human-machine interaction research for in-vehicle information and warning systems.

2.1 Human centred design process

In order to develop an easy and understandable system, suitable for its users, it is important to know what the users really want and need. One way to assure this is to guide the work by the standard for human centred design processes for interactive systems - ISO 13407. The goal of the process is to get a good quality of the interaction between the person who uses the product and the product itself. (EMMUS, 1999)

ISO 13407 emphasizes the need of four user centred design activities, preferably implemented iteratively:

1. Specify the context of use
2. Specify user and organisational requirements
3. Produce design solutions
4. Evaluate designs against user requirements

(International Organization for Standardization, 1999)

A user centred design has also to include an active involvement of users. Users should participate during the entire development process to be able to express their needs. It is especially important early in a product’s life cycle, when it is not expensive to do changes. The result is an avoidance of building functions not requested and accepted. (Gulliksen & Göransson, 2002)

The first design activity, specifying the context of use, should for example include a hierarchical breakdown of tasks and a description of the environment in which the user will use the system. Analysing the driver task does help with understanding what the system has to be able to support. (Laberge, Creaser, Rakauskas, Ward, 2006) The most common methods to use when conducting a task analysis are interviews and observations. (Gulliksen & Göransson, 2002)

Before the system can be designed it has to be specified. This is the second design activity. Specifying requirements aims at converting the insight of the context into explicit requirements for an appropriate system. (EMMUS, 1999) Requirements should describe what to be done, but not how. This to avoid thinking in solutions before the creative processes are started. Furthermore, the requirements should be prioritised (must requirements and should requirements) to be able to set a focus on the most important issues in order to develop a system that fulfils its purpose. (Gulliksen & Göransson, 2002)

There are several methods available to use when collecting requirements, for example questionnaires, focus groups and interviews. A focus group is a controlled group discussion with users about a specific topic. Interviews can be either unstructured (discussing about a theme), structured, or something in between. Structured interviews resemble a formulary, where all respondents are asked the same questions. It is however important to keep in mind that user's needs are not always the same as what they express verbally and therefore observations are a good complement. (Gulliksen & Göransson, 2002)

The third design activity is to create different concrete concepts. Concepts could be seen as general design ideas of the interface appearance. To be able to stimulate creativity different methods can be used. Analogies refer to thinking of other devices that solve a related problem but in an unrelated area of application. Thinking of associations to randomly collected words can also be useful. The associations could then be related to the problem at hand. (Hamrin & Nyberg, 1993)

There are several methods for representing design ideas. In early stages paper visualisations are recommended. When the design does not seem to be finished, it is easier to give important critique and qualitative feedback. Designers also get more prone to listen to the feedback and change design solutions since the paper visualisations effortless could be created and thrown away. This gives a possibility to create a design gradually and explore different solutions during evaluations. Design and evaluation should be done iteratively. This is supposed to be carried on until the design meets the user and the organisational requirements. (Gulliksen & Göransson, 2002)

There exist several methods for evaluating the design in a user centred process. Some of them have a direct user contribution (for example interviews) and some are more indirect (for example observations and expert evaluations). An expert evaluation is characterized by one or several experts in the domain of the application going through the design solutions looking for problems. (Gulliksen & Göransson, 2002)

2.2 Design guidelines

2.2.1 Warnings - trust and acceptance

The effectiveness of warnings depends on users' trust and acceptance, and relies on whether the warning is capable of influencing an individual's behaviour. A successful warning will be detected, correctly interpreted and acted on. It must therefore draw the attention of the driver, the message has to be cognitively understood and then accepted. (Chengalur, Rodgers, Bernard, 2004).

Two different kinds of warnings can decrease driver acceptance and trust in the warning system. False alarms refer to warnings that are trigged in the absence of an appropriate stimulus. For example, if the driver gets a warning about a bicyclist when there are no bicyclists in the vicinity of the car. Nuisance warnings refer to a subjective component, a warning that is caused by an appropriate stimulus but is perceived by the driver as inappropriate for some reason, such as timing or frequency. (Campbell, Richard, Brown, McCallum, 2007)

When trust is too low and a warning is presented, drivers may spend additional time verifying the problem, or they may choose to ignore the warning. A study shows that if false warnings occur indicating a need to break (but breaking is not required) drivers do not brake reflexively to imminent alerts in situations when breaking is necessary. There is thus a need to prevent false or nuisance warnings. (Campbell et al., 2007)

Campbell et al. (2007) have recently conducted a comprehensive review of the last 10 years best-available human factors literature. Focus was set on the effective implementation of crash warning system interfaces that emphasize driver performance and safety. They identified key strategies for minimizing the frequency and impact of false/nuisance warnings. For example, control functions with parameters that should be adjustable to the driver include turning the system on and off and modifying intensity or volume of the alert (e.g. brightness or loudness). Other strategies include the timing of warnings. For information about timing see chapter 2.2.7. Another way to minimize false warnings is to present a warning only after a target or critical situation has been detected as continuing for some specified minimum time. (Campbell et al., 2007) With a continuous evaluation of the risk level, a warning can be given to the driver after the risk level has approached a prior specified threshold. (Meinken et al., 2007)

Too much trust in a collision warning system can however also reduce system effectiveness. Campbell et al. (1996) mention that too high trust in a system may lead to drivers neglecting other typical safety behaviour, such as being attentive to other road users. (Campbell, Hooey, Camey, Hanowski, Gore, Kantowitz, Mitchell, 1996)

2.2.2 Number of warning stages

Warnings provided during a situation preceding a potential crash can be divided into two different categories; Imminent Crash Warnings (ICWs) and Cautionary Crash Warnings (CCWs.) An ICW requires an immediate corrective action and should occur rarely, due to their intrusive nature and the need to maintain a perceived sense of urgency. A CCW requires attention and provides a preparatory warning cue to the driver that an emergency response may be necessary. (Campbell et al., 2007)

The data on number of warnings are mixed. Various researchers reach different conclusions. Earlier it was indicated that all warning devices should generate at least two levels of warnings, but more recent efforts have identified some uncertainties regarding the optimal approach. Campbell et al. (2007) have put up the following table (table 1) as a guideline.

Number of warnings	Advantages	Disadvantages
One-Stage (ICW only)	• May best address distracted-driving situations • Use if the rate of false alarms associated with two-stage system significantly reduces driver trust in the system or increases driver frustration • May be simpler for drivers to comprehend • Avoids driver confusion or potential ineffectiveness arising from cautionary warnings	• May provide less time for the driver to recognize and respond to an emerging crash situation
Two-Stage (CCW + ICW)	• May minimize requirements for hard braking • May assist drivers in developing a coherent mental model and better awareness of the warning system device • May reduce startle effects from ICW alones • May aid drivers in anticipating potential crashes	• May increase likelihood of real or perceived false alarms • May reduce driver trust and use of the system due to false alarm

Table 1: Advantages and disadvantages of using one-versus two stage warnings. (adapted from Campbell et al., 2007)

2.2.3 Make warnings compatible with driver responses

For a warning to be effective, it has to be perceived, understood and correctly acted on. (Chengalur et al., 2004) It is therefore important to design warnings that elicit a response from the driver that is consistent with the action needed to properly respond to the driving situation. This could reduce response times and also generate fewer response errors. (Campbell et al., 2007)

Moreover, cars will be increasingly filled with different warning systems. If it exists a lot of systems with similar warning strategies it may be difficult to discriminate one warning from another and thereby a confusion of how to respond may occur. Different warnings have therefore to be easily distinguishable to the driver. (Campbell et al., 2007)

2.2.4 Prioritise warnings

Multiple studies have identified a decrease in performance associated with perceiving, processing and responding to more than one stimulus simultaneously. These decrements are especially a problem when the stimuli are presented via the same perceptual modality, for example two visual messages. Since many driving tasks draw on the same perceptual and cognitive resources, warnings need to be prioritised. The limitation is that humans are serial processors of information, at least when it comes to the same perceptual modality. Attention is for example an information-processing bottleneck that can only process one stimulus or piece of information at a time. This leads to more time-consuming sequential execution. Another example is that if two visual stimuli are presented in rapid succession, the response to the second stimulus is delayed. If the time between the two stimuli is very short (less than about 100 msec), a different processing sequence occurs. Both responses are emitted together and both are delayed. (Wickens & Hollands, 2000)

Given the safety relevance of collision warnings, it is important to emphasize the priority of collision warnings over non-collision warnings. It is also important to prioritise collision warnings from different systems and from different stages within the same system (e.g. ICW versus CCW). Multiple warnings occurring simultaneously should be prioritised in terms of severity and urgency. To be able to prioritise warnings Campbell et al. (2007) recommend using an International Organization for Standardization standard, ISO 16951. (Campbell et al., 2007)

2.2.5 Information modality

When designing a warning or a supporting message, the modality is of great importance. It may be visual, auditory, tactile (refers to mechanical vibrations, pulsing or counterforce) or a combination of these modalities. Each modality's advantages and disadvantages could be seen in table 2. (Lee, Perez, Doerzaph, Stone, Neale, Brown, Knipling, Holbrook, Dingus, 2007)

Advantages	Disadvantages
Visual Information	
• Good for complex information • Directional cueing • Could give more information than auditory signals • Good to provide continuously available information • Good for non-urgent information • Good for spatial information (visual images) • Notable in nosy environment	• Eye fixation required • Could be language dependent • Not omni-directional, can therefore not be relied upon to capture the driver's attention • Visual overload if too much
Auditory Information	
• Omni-directional, can command attention regardless of where the driver is looking • Reduce visual workload • Directional cueing • Could describe urgency levels better than tactile warnings • Reduces perception-reaction times • Improves driver awareness of warning/information • Good for time-critical information that requires attention • Good for few and short messages	• Could become annoying and may be turned off • Difficult to accommodate hearing impaired drivers • Signal detection problem under high ambient noise conditions • Could cause unwanted "startle" response • Not discrete and personal • Not good for frequent messages • Not good for continuous information • Auditory overload if too much
Tactile Information	
• Omni-directional • Good for simple urgent info that requires attention • Reduce visual and auditory workload • Consistent with driver's mental model • Notable in noisy environment • Appropriate to present high priority alerts and warnings • Discrete and personal • Small number of competing demands for this source	• Potential for misperception as a mechanical failure • Unable to convey detailed information • Require some learning to distinguish from natural driving sensations • Only effective if the driver is in contact with the tactile source • Can be annoying • For now there is insufficient data to claim that tactile ICWs are equally effective as auditory ICWs

Table 2: Modality evaluation (Campbell et al., 2007; Chengalur et al., 2004; Dewar & Olson, 2007; Pierowicz, Jocoy, Lloyd, Bittner, Pirson, 2000)

2.2.5.1 Type of visual display

When providing a driver with visual information, the location and type of display have to be considered. Different display types (see table 3) are appropriate for different objectives. Examples of different objectives are given beneath the table.

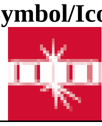
Display type	Explanation	Comment
Analogue Display 	Graphical representation of continuous information (scale or looming)	
Discrete Display  ON OFF	Binary on/off information (for example light emitting diodes)	Effectiveness depends on presentation context conveying correct meaning
Digital Display 	Number information	Lacks clear cues that warning or alert stages are reached
Alphanumeric 	Message in full or abbreviated form	Only appropriate for non-time-critical complex information
Symbol/Icon 	Simple graphic signs that transmit message information	

Table 3: Various visual display types (adapted from Campbell et al., 2007)

If the message is to modify behaviour (for example getting drivers to adopt longer headways), a continuous feedback provided by an analogue display is preferred. If the message is time-critical (for example an ICW) it is important that the display captures the driver's attention and is easy to understand. In this case, the best display would involve an icon/symbol or discrete display that appears abruptly within the field of regard. If the meaning of the message is obvious from the context a discrete display is appropriate, but if the meaning must be conveyed an icon/symbol is better. Icons may however require some level of information processing. (Campbell et al., 2007)

The location of the display is also very important since drivers' forward view is connected to other road users' safety. Glances off-road are highly tied to crashes. (Dewar & Olson, 2007) A display that attracts driver attention away from the forward scene, at a critical moment, would therefore be undesirable. (Campbell et al., 2007)

Data from driver eye fixations studies suggest that drivers feel comfortable looking inside a vehicle for about one second on average though sometimes, longer durations are acceptable. As the demands on driving increase, drivers spend less time looking on second important targets. A driver's eyes are therefore less likely to be directed into the vehicle as the road becomes more complex, for example in an intersection. (Dewar & Olson, 2007)

A thesis work has examined what information to present over the steering wheel. For high priority information which seeks the driver's attention and is related to the driving task (e.g. critical warnings, navigation and speed), a Head-Up Display (HUD) was recommended. Information with lower priority (e.g. less critical warnings and the status of various systems) can be placed in a lower position. A Head-Up solution implies that the important information is reflected on the windscreen in the driver's line of sight. The advantage is that it increases the likelihood that the information will be seen. In addition the time that the driver's gaze will be pulled away from the forward view will be reduced. Drivers do not have to look away from the traffic for too often or too long since they can be looking at the display and see traffic peripherally at the same time. (Sandberg & Sennvall, 2005)

Another important design issue is the physical grouping of displays. A centralized approach refers to information centralized on a single screen and a distributed approach to information across several locations. With a centralized approach, the driver does not have to visually scan more than one single display. On the other hand, display location can act as a code to identify the urgency or type of the displayed information. This may reduce processing time and aid driver interpretation, decision-making and response. This indicates that a centralized approach may be more effective with relatively simple stimuli, but that the distributed approach could be more effective when a large number of messages can be divided into a small number of meaningful categories. (Lee, Gore, Campbell, 1999)

2.2.5.2 Type of auditory signal

There are different types of auditory signals; speech, tones and auditory signals. Tones are single or grouped frequencies presented simultaneously and auditory icons are naturally occurring everyday sounds that relate to the situation it is presented in. For example, the sound of a coin falling into a slot conveys that an automated toll payment is completed. (Chengalur et al., 2004) For auditory signal characteristics see table 4.

Advantages	Disadvantages
Tone	
• Under normal conditions, demands less attention than voice • Language independent • Good to present high priority alerts and warnings • Produce shorter reaction time than speech messages when used in conjunction with a visual display, but some contradicting results have recently been found	• Unable to convey detailed information • The meaning of a tone is not inherently known and must be learned by the driver • An unfamiliar tone could produce an inappropriate response
Speech Message	
• Able to convey detailed information • More information than a nonverbal • Best for information that are not time-critical • Good for flexibility in message content • Appropriate when message must be dealt with over the long term, such as “congestion ahead in 10 km”	• Language dependent • Under normal operating conditions, may demand more attention than tone • Some evidence that false alarms presented via speech display will be associated with greater levels of driver annoyance than false alarms presented using tones • Requires more time to comprehend than tone or auditory icon
Auditory Icon	
• More easily learned than a tone • Better than speech message when immediate response is required • Reducing a driver’s reaction time compared with speech or tone • Intuitively convey information about the object or action they represent	• A naturally occurring sound could potentially confuse the driver and initiate an unwanted response • Only effective if sound are relevant to the situation • There is not much research of auditory icons as in-vehicle warning signals

Table 4: Evaluation of auditory signal (Campbell et al., 2007; Chengalur et al., 2004; Dewar & Olson , 2007; Lee et al., 2007; Pierowicz et al., 2000)

2.2.5.3 Type of tactile display

The type of tactile display should be associated with the situation it represents and if possible be compatible with the driver response appropriate for the driving situation. Data on the efficacy of tactile crash warnings is for now limited and mixed. (Campbell et al., 2007) The following table concludes some important issues derived from different studies.

Display type	Comment
Accelerator counterforce	• Driver's foot has to always be on the accelerator and the warning will be effective only if the driver is in contact with the tactile feedback source. • Has in some forward collision studies been proven to yield improved crash-avoidance. It seems to lead to drivers releasing the accelerator faster in braking manoeuvres.
Accelerator vibration	• Driver's foot has to always be on the accelerator and the warning will be effective only if the driver is in contact with the tactile feedback source.
Brake pulsing (one or more short, sudden jerks of deceleration)	• Brake pulse warning for ICW appears to be less effective than auditory ICW. • Potential loss of vehicle control on slippery surfaces. • Drivers may mistakenly assume that a brake pulse warnings will automatically mitigate an unsafe situation.
Steering wheel vibrations	• Has not the natural mapping to braking response and do therefore not seem to be effective in reliably alerting the drivers and prompting appropriate responses.
Steering wheel torque	• Has not the natural mapping to braking response but to steering behaviour. It advises drivers to steer against the force. • Will be unsafe and not work if the steering wheel is in centre position.
Seat vibrations	• Has not the natural mapping to braking response and do therefore not seem to be effective in reliably alerting the drivers and prompting appropriate responses. • Older drivers are less sensitive to vibrations.

Table 5: Tactile display types (Campbell et al., 2007)

2.2.6 Design characteristics

To be able to detect a message it has to be identifiable and distinguishable from the background regardless of weather, light and sound conditions. For visual warnings this concerns location, size, shape, contrast and colour of the information. For auditory warnings it includes; patterns, sound level and sound spectrum, and for tactile warnings; frequency, amplitude and duration are of importance. To be able to interpret the information it is furthermore essential to use users' language. (Chengalur et al., 2004)

2.2.6.1 Message style

There are different types of visual and speech messages. Notification messages (e.g. "vehicle to the right") advise the driver of a situation but leave him/her to both interpret the situation and decide how to respond to it. Command information, on the other hand, suggests a specific course of action (e.g. "slow down" or "STOP"). Command-style messages have a greater compliance and can reduce the information-processing activity, for example important in conditions for high stress and time pressure. Commands have however also the potential to misdirect drivers if the system fail to consider all relevant factors. This could also undermine trust in the system. (Lee et al., 1999)

To draw attention to a visual message it has been proven that items that are large, bright, colourful and changing (e.g. blinking) are useful. An abrupt stimulus onset (e.g. a light turning on) also functions as an attention drawer. (Wickens & Hollands, 2000) It is easier for a driver to detect a change from nothing to something, than it is to detect a change from something to something else. (General Motors Corporation, 2002) In addition, if messages take over part of the display when they appear, they do not disappear in the rest of the information on the display. (Sandberg & Sennvall, 2007)

Imminent visual stimuli should provide information about the nature of the hazard. This could either be through associated icons or through the context (for example an indicator to the left, inducing an orienting response by causing the driver to look in the direction of the hazard). If used with auditory or tactile signals the visual message could not only provide complementary information about the nature of the warning, but also redundant information. Each information channel should explicitly and independently show the severity of the message. (Campbell et al., 2007)

2.2.6.2 Colour

The purpose of using colours is to improve safety, visibility and increase efficiency of the information given. Colours could also be used to make warnings compatible with driver responses, since certain colours have well-established symbolic meaning. The colour red indicates “stop”, “danger” or “not okay”, yellow indicates “caution” and green indicates “okay” or “go”. Although red is normally associated with danger, it is also used in instrument panel indicators (for example seat belt icon) that drivers see frequently. There is therefore a risk that high-priority warnings could be confused with the non-critical icons, especially if they are presented near each other. (Campbell et al., 2007)

Colours should however not be overused since many colours in a small area make the display hard to read. No more than five or six colours should therefore be used in a display to guarantee that the meaning of a colour will not be misidentified. (Wickens & Hollands, 2000)

Every tenth person has a defect, colour blindness, which makes them not experiencing colours as the majority. The following should therefore be taken under consideration.

- Colours easy to read for everyone are black, white, yellow and blue.
- To get attention or warn red is usually recommended, but for colour blind people red is not an intense colour. To catch their attention a glaring yellow is best, but yellow could however sometimes be mistaken for green.
- Never use red and green together, since a red object could disappear in a green background.
- Colours put together in patterns are harder to discriminate.
- Colours put together in a small area are difficult to distinguish.

(Törnqvist, 1997)

2.2.6.3 Icons/symbols

Most studies demonstrate that icons can provide distinctive advantage over text messages, since they minimise what the driver needs to read. Text messages require more attention, resulting in increased workload. (Wickens & Hollands, 2000)

When deciding what icons to use, new or well-known symbols can be derived. Using an icon that already exists has the advantage that it is already associated with something. Therefore the meaning does not have to be learned. It is important though to keep in mind that although a symbol may clearly depict a recognizable object, it can be ambiguous concerning the meaning of the object in the given context. For example, an arrow could be interpreted as pointing to a region, or as pointing as a commanding action in a given direction. (Wickens & Hollands, 2000)

Information could be redundantly coded across shape, colour, scale and icon size. Using shape coding of warning signs could lead to a derived approximate meaning from the shape alone (e.g. an octagonal sign indicates that it is a stop sign). (Chengalur et al., 2000)

2.2.6.4 Auditory signals

The purpose of auditory signals is to draw the driver's attention to a potential crash threat by localizing the sound in the direction of the threat. A signal could also be used to draw the attention to a visual warning display. Auditory warnings should convey different levels of the subjective impression of urgency. The urgency level should be consistent with the urgency of the potential crash conflict. To convey different levels it is, for example, possible to vary the speed of the signal, the rhythm, the pulse duration, the intensity and the frequency. One very important issue to consider when using auditory signals is the trade-off between a warning alerting the driver and annoying him/her. (Campbell et al., 2007)

Most studies recommend that auditory warnings should be reserved for ICWs use only. This to maintain high-level urgency associated to the signal and to minimize driver annoyance, since other information occurs more often. To be able to discriminate between different signals, vehicles that are equipped with more than one crash warning system should use distinguishable signals. Furthermore, other conflicting auditory signals should be reduced in volume during the presentation of the warning. (Campbell et al., 2007)

2.2.7 Timing of supporting information and warnings

The timing of a warning is critical to its usefulness. It should not be given too late or too early. Thresholds should be set as not to violate the expectations of the driver and should be presented after an attentive driver would normally make control inputs. Warnings given before the moment the driver would normally react (steering away, releasing the accelerator, or braking) may be viewed as nuisance alarms and thereby reducing the acceptance of the system. It is therefore important to use driver-vehicle control input to determine the timing of alerts and warnings. (Pierowicz et al., 2000) To get insight into approximate normal driver behaviour, Lee et al. (2007) describe a study conducted by General Dynamics. The study determined normal driver behaviour when approaching stop-sign intersections. Only a small sample size (19 drivers) was however used. Results show that drivers released the accelerator about 9.3 seconds before entering the intersection, applied the brakes about 7.27 seconds from the intersection entry and activated the turn signal about 6.6 seconds prior to intersection entry. Steering did not occur until 0.8 seconds prior to entering the intersection. (Lee et al., 2007)

When referring to the length of a warning it may be advantageous to suppress an auditory warning as soon as the driver applies the brakes, since the driver is presumably aware of the potential crash situation at that time. Visual information about an intersection could though be presented during a longer time since it is not as intrusive. (Campbell et al., 2007) Information should however not be presented after the driver has passed the intersection. (Volvo Cars, 2007b)

Determining timing is complicated since humans are characterized by great variability. Human perception of the same conditions, for example gap acceptance, could vary a lot. The same gap may be too liberal for one person, while being too conservative for another. Gap acceptance could vary between different drivers, but could vary for the same driver as well. This could for example be the case under different traffic volume conditions. Drivers are more likely to accept smaller gaps if wait times are longer. (Pierowicz et al., 2000) The variability among humans indicates that sensitivity settings should be provided. This to modify the timing of the warning according to driver preference and thereby reduce nuisance alarms. The timing must however be bounded by a minimum time necessary to avoid a hazard. (Campbell et al., 2007)

2.2.7.1 To take into account when creating a timing algorithm

Creating a timing algorithm is a complicated task that has to include several factors. It is important to be able to recognize the position of vehicles, on what road segment the own and other vehicles will enter and whether a driver intends to turn or not. This to be able to present warnings and traffic rules right. Included in any warning timing algorithm must also driver response time be; how much time passes before the vehicle starts to decelerate. This includes time to notice a stimulus and react, e.g. time to accelerator release and time from accelerator to brake. Furthermore it has also to be determined how long it takes for the vehicle to stop. This includes for example taking distance to required stop (due to signs, traffic signals or potential crash situation), vehicle velocity, deceleration and roadway condition under consideration. It is also important to take into regard that drivers' brake diversely hard. (Lee et al., 2007)

Great deal of research on perception-response time has been made, but some studies criticize attempts to seek a canonical brake reaction time, RT. Reactions to the braking of the lead car differs for example definitively from reactions to a crossing vehicle at an intersection. Instead a brake RT model should take situational and driver variance into account. Variables affecting the RT could for example be expectations on the situation, the traffic situation and the need for the response, age and cognitive workload. A major determinant of drivers' reactions is urgency or criticality (the time distance to an impending collision or threat). This because space and time margins to stop the car affect drivers' reaction times. It has been proven that the higher the speed, the shorter the response and regardless of speed; the shorter the distance the shorter the response. (Summala, 2000) Dewar & Olson (2007) have, on the other hand, found that the time required to respond depends in large on the intensity of the stimuli, the amount of information required to process and the complexity of the decision-making process. (Dewar & Olson, 2007)

When negotiating an intersection, drivers face various situations where warnings and information can be triggered. Studies have been made on timing of different information. Pierowicz et al. (2000) have for example made recommendations when to advise the driver that it is unsafe to proceed, if he/she is located at the point of intersection entry. Rössler et al. (2005) have recommended taking calculations derived in reports from the National Highway Traffic Safety Administration (NHTSA DOT HS 808 143, 1994 & NHTSA DOT 808 164, 1994) into account. They include algorithms for timing of messages when the aim is to stop in front of an intersection (due to traffic, signals or signs) or within an intersection due to a potential colliding vehicle. An algorithm also exists if the aim of system is to inform the driver prior to the point where normal deceleration should begin. A summarisation of the algorithms can be read in Rössler et al. (2005).

3 Method

This chapter describes the working procedure of the thesis, methods chosen to conduct the work and how information was gathered. It also gives an explanation to why certain choices have been made.

The work within this thesis has been guided by the standard for human centred design processes for interactive systems - ISO 13407. This since it is important that the system is suitable for drivers and easy to understand and use. The choice of method is also in line with Volvo's design philosophy:

> ”Good design in not only a matter of styling the surface.
> It is just as important to make the product easy to
> understand and use. If the product is not functional,
> it can't be beautiful.” (Volvo Cars, 2007c)

The following figure describes the sequence of design activities used within this thesis. Dotted lines represent ways to go if further research and development will be done. The design activities are described in detail below.

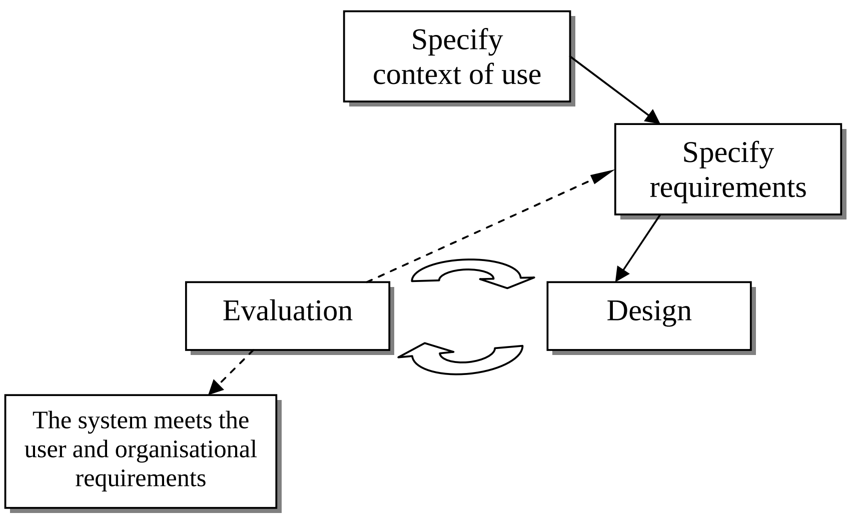


Figure 1: The sequence of user centred design activities used in this thesis.

3.1 Context of use

The first design activity, specifying the context of use, included describing the environment in which the driver will use the system and analysing the driver task. When collecting information about the environment, different motor vehicle industries' homepages and a human-vehicle interaction expert at Volvo Car Corporation were consulted. In this way, insights in features and equipments of both existing and future cars were gained.

Regarding analysing the driver task a lot of studies have already been done. A literature study of existing task analysis was therefore made to be able to yield a systematic description of user activities. Existing studies vary in detail, but tend to be very generic when describing intersection in general and very detailed when describing a certain scenario in a certain kind of intersection. An example of the latter one is when turning left in a signalised four-legged intersection. Furthermore, studies about accidents and information processing bottlenecks in intersections were reviewed. This in order to find requirements on a system that will reduce the strain of the driver in overburdened traffic situations that can contribute to driver errors.

3.2 User requirements

During the next design activity, lists of requirements were put together. They were derived from the guidelines in chapter 2.2. They emphasize general factors important to gain system usability and driver safety. Regarding specific requirements on the output of the support and warning system, two different approaches were used. Information about accidents and information processing bottlenecks in intersections were, as mentioned in chapter 3.1, reviewed during the analysis of the context of use. This conduced important information about what tasks the system should be able to support. It is however also important to find out what kind of assistance drivers would accept in an intersection, how they would like to interact with the system and which main features they would like and accept to be present. User requirements identified in two different European projects (for an description of the projects see chapter 5.2) were therefore summarised. The projects are interesting since their aim to reduce collisions at intersections is similar to the aim of the intersection system developed by Autoliv, VCC and Chalmers University of technology. More indications on users' requests were however gained from private structured interviews.

The structured interview form was used since it was important to get users opinions about certain questions. During the interviews it was possible to identify and clear up misunderstandings. The respondents also got the possibility to express factors important to them, but not included in the questions. In addition, it was possible to find out more information in terms of why the respondents answered the way they did, what they would think about such a system in general and if there are certain situations in which they think the system would be especially useful. The questions (see appendix A) was put together from insights from the context of use. The interview respondents consisted of eight active drivers in the age between 23 and 62. Half of them were women and half of them were men.

Before the respondents were contacted a pilot interview was carried through. This to know if the questions were understandable and if something important was missed out. The results from the interviews were seen as a first indication on what drivers would like to have in an intersection support and warning system. The proceeding design and evaluation process gave more insights in what drivers want and are willing to accept.

3.3 Design process

The next stage was to create different potential design solutions. First decisions about message location and modality were made from the guidelines in chapter 2.2. After that, suggestions for system output were divided into different subgroups. To be able to generate concrete design concepts for each subgroup, driver scenarios were generated. The scenarios describe problematic situations for the drivers, where an intersection system could be of good use. Concepts were then generated for each subgroup with regard to the belonging scenario. The concepts were either modified from existing icons or developed using drawing tools.

Using tools to stimulate creativity (see chapter 2.1) resulted in many paper-and-pencil sketches. Some of them had to be redesigned and some had to be excluded. This in regard to users' requests and to requirements important to gain system usability and driver safety. The sketches were then turned into an interface using computer drawing tools. To be able to finally choose what concepts to evaluate, discussions with human-machine interaction experts took place. Experts in human-machine interaction have an experience from design and development of driver-vehicle systems and could therefore contribute with important knowledge of the area and feedback for redesign. After the discussions, some modifications were made before the concepts were evaluated.

3.4 Concept evaluation

The evaluation within this thesis was conducted with a direct user contribution with active drivers. The respondents were a mix of University students and people working at Volvo Car Corporation and at Lindholmen Science Park. None of them had participated in the interview study. Eighteen drivers were interested in participating but only fourteen of them appeared (eight males and six women) in the age between 21 and 57.

During the evaluation the driving scenario were read to the respondents and opinions about the concepts were captured through an evaluation form (see appendix C). All concepts of a specific subgroup were shown and explained before the respondents were asked to express their opinions. This because it is easier for a respondent to form an opinion of a design concept if he/she can judge it towards something else. The evaluation form included the most important factors to evaluate; placement, strain, interpretation of icons, interpretation of urgency, information content and general impression. In addition, the respondents were asked if they would like to have the system and whether or not they would pay extra to get it when buying a car. The respondents were also asked to prioritise the importance of the system output. When filling the evaluation form out, grades from 1 to 7 were used. This to be able to easily compare a driver's opinion regarding different concepts. More interesting than comparing different concepts with grades, is however drivers' positive and negative comments about the concepts. The respondents were therefore asked to thinking aloud, discussing and motivating their opinions in words.

Before the evaluations took place a pilot study was carried through to know how much time a respondent would need to spend and if the questions were understandable.

4 Context of use

The factors analysed in this chapter emphasize the potential resources available for the design and highlight information that may be critical for drivers to perceive to be able to pass an intersection safely.

4.1 The users' physical surrounding

To be able to develop a concept for a future driver-vehicle interface for intersection support, it is important to know what potential features and equipment upcoming cars will have. Both interaction equipments (see figure 2) and systems for supporting, alerting and warning drivers in different situations (see table 6) are of interest. This since they constitute the conceivable resources available for the design.

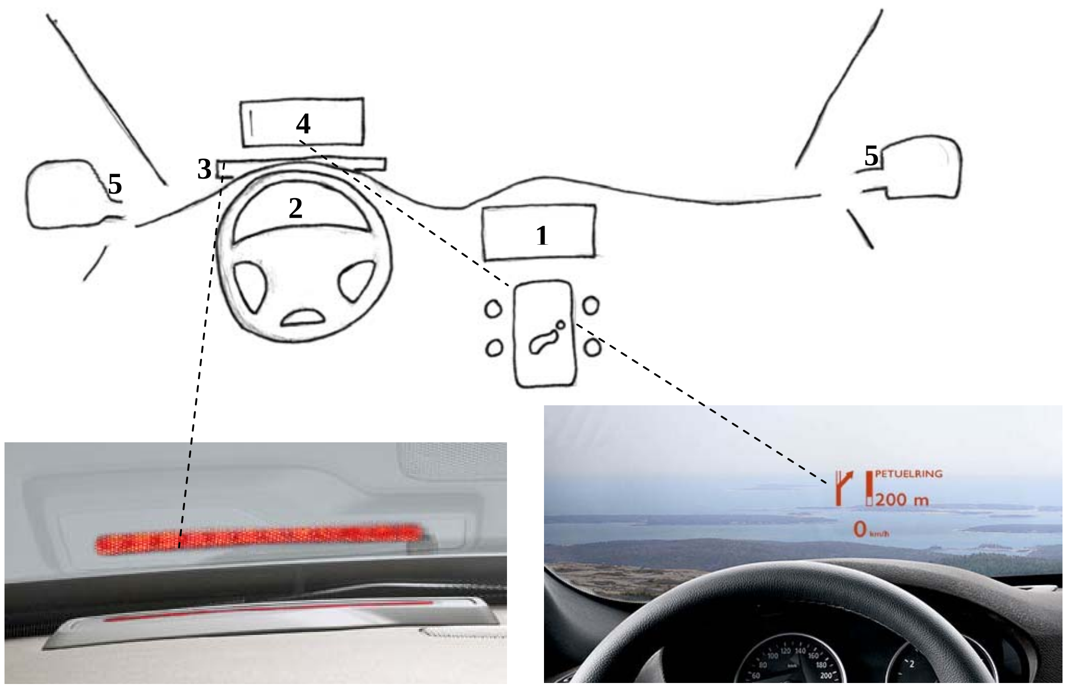


Figure 2: Potential equipments available in future cars

1. Centre Stack Display, a colour graphic display
2. Instrument cluster display, a colour graphic display behind the steering wheel
3. LED - Light-emitting diode ramp, gives a red light on the windscreen
4. HUD - Head-Up Display, information is reflected on the windscreen in the driver's line of sight. Usually offer information regarding speed and turn-by-turn navigation.
5. Light-emitting diodes

There are also loudspeakers that could give an audible alarm from different locations. Drivers could possibly also be surrounded by tactile features such as accelerator counterforce, brake pulsing and vibrations in the steering wheel. (Campbell et al., 2007)

SUPPORT AND WARNING SYSTEMS IN VOLVO CARS
• **Collision warning with auto brake**
The collision warning with auto brake alerts the driver with purpose of helping him/her avoiding or reducing the severity of a crash with a vehicle driving in front. If a crash is likely to happen, the system will alert the driver with a flashing red warning light (see number 3 in figure 2) on the windscreen and an audible alarm. The system also supports driver-initiated braking by obtaining swift brake response. This is done by pre-charging the brakes and preparing for panic brake application. In case of the driver not reacting to a warning and a collision is imminent, the brakes will activate automatically. (Volvo Cars, 2007e)
• **City Safety**
When driving at low speeds and coming too close to an obstacle (for example a pedestrian) and a collision is imminent, the city safety system will automatically brake the car without warning the driver. (Agardh, 2007)
• **Intelligent Driver Information System, IDIS**
IDIS constantly analyses the driver's workload and driving situation. If necessary, it momentarily delays some information from the car's onboard systems, such as the integrated phone. It also minimizes unnecessary warnings in the driver information module. The purpose is to avoid unnecessary distractions in critical driving. (Volvo Cars, 2007e)
• **Navigation system**
The navigation system guides the driver from one location to another. A map with recommended drive and distance left to the desired destination is shown on the centre stack display (see number 1 in figure 2). Furthermore, audible instructions guide the driver when to turn in an intersection. The system also holds information about public establishments, for example post offices, as well as traffic and road information. (Volvo Cars, 2007d)

Table 6: Some available supporting and warnings systems in Volvo cars

4.2 Task analysis

Negotiating an intersection is a complex and demanding task. As drivers approach, a number of factors influence their journey; signs and signals, oncoming and crossing traffic and the number of crossing lanes. The driver can encounter different potential conflict situations. He or she must under a short limited amount of time assimilate large amount of information, make decisions and execute a desired action. Many of these tasks draw on the same perceptual and cognitive resources. (Caird & Hancock, 2002)

The following task analysis (see table 7) describes a driver's tasks in any kind of intersection, whether signalised or not. The analysis consists of a task with a goal and is modelled as a hierarchy of subtasks. These comprise different perceptual, cognitive and behavioural aspects of negotiating an intersection. The subtasks are necessary to be able to accomplish the goal. The subtasks are in an approximate temporal order, but due to trying to describe tasks in any kind of intersection some subtasks are not always required. To clarify when different tasks need to be accomplished, figure 3 below shows an example of some of the segments from the task analysis in table 7.

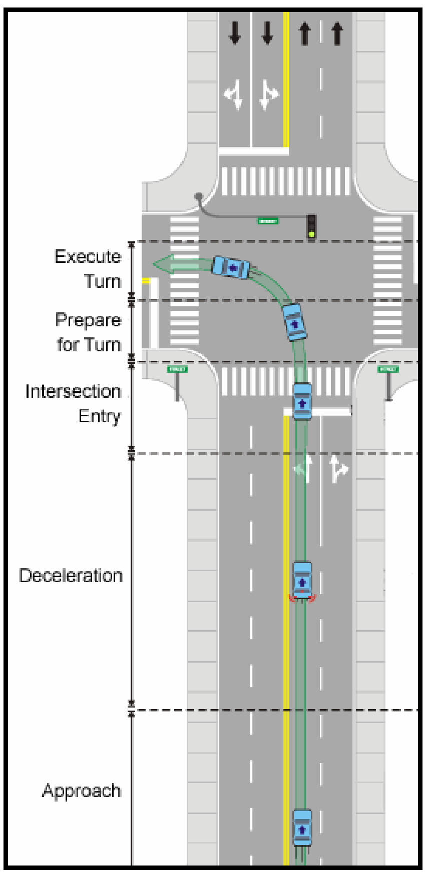


Figure 3: An example scenario diagram showing segments from the task analysis (adapted from Richard et al., 2006)

Driver's goal: negotiate an intersection to be able to continue the journey to a specific destination	
Tasks	Subtasks
1. Preparation of entering intersection	
1.1 Approach	1.1.1 Identify intersection characteristics 1.1.2 Identify upcoming intersection as localisation of turning or proceeding through 1.1.3 Gather information about the situation and understand situation, signs and signals (for example lights about to change) and unsafe situations
1.2 Enter correct lane (if required)	1.2.1 Determine if already in desired lane 1.2.2 If not, determine if a lane change is feasible/safe by scanning for conflict vehicles and gaps 1.2.3 Activate turn signal 1.2.4 Change lane
1.3 Decelerate/stop (if required)	1.3.1 Activate turn signal (if required) 1.3.2 Stop at the intersection or slow down to turning speed
2. Entering intersection	
2.1 Decision to proceed	2.1.1 Check surroundings for unsafe situations 2.1.2 Determine if there is sufficient time to turn/proceed and whether it is safe to do so
2.2 Intersection entry	2.2.1 Get into position to turn or to proceed 2.2.2 Quickly check for potential hazards (e.g. red-light runners, oncoming vehicles, VRUs or hazards in the path)
2.3 Prepare for turn/proceeding	2.3.1 Detect approaching traffic and gaps 2.3.2 Estimate gaps 2.3.3 Decide if it is safe to continue
3. Traverse intersection	
3.1 Execute turn or proceed through intersection	3.1.1 Determine when to initiate manoeuvre and/or accelerate 3.1.2 Manoeuvre the car in the right direction

Table 7: Task analysis for intersection negotiation (Richard et al., 2006; Laberge et al., 2006; Caird & Hancock, 2002)

4.2.1 Information processing and crash data analysis

An understanding of intersection crashes is necessary to be able to identify which of the tasks from table 7 that are providing drivers with the most problems. It is important that the system somehow supports drivers in these problematic tasks.

A variety of driver errors for different intersections have been specified by different researchers, see for example Caird & Hancock (2002), Laberge et al. (2006) and Pierowicz et al. (2000).

- Failure to detect other vehicles and vulnerable road users. This could be due to visual obstruction, reduced visibility, distraction or misinterpretation of information and “looking but not seeing”.
- Failure to detect or comprehend signs and signals. Could be due to driver distraction by in-vehicle or local surrounding factors.
- Failure to judge presence, size and safety of gaps. Could be due to failure to accurately estimate velocity of approaching traffic, to estimate time to accelerate or to estimate own movement relative to other vehicles.
- Failure to anticipate the actions or intentions of other drivers and vulnerable road users, for example due to a common disregard of control devices by both motorists and pedestrians.
- Failure to coordinate travel within the intersection in accordance with the timing of the lights.

Richard et al. (2006) have conducted a different approach of analysis. The analysis identifies the information processing bottlenecks that drivers face when negotiating an intersection. Bottlenecks could occur due to time constraints or due to conflict tasks drawing on the same resources and the bottlenecks therefore represent situations in which drivers may become overloaded by driving demands. These situations could result in drivers conducting important tasks improperly, e.g. taking too quick look at oncoming traffic and thereby failing to see an oncoming vehicle, or skipping certain tasks altogether. Drivers overloaded with demands could thereby lead to accidents and near-to-accident conflicts. In these situations drivers could benefit from countermeasures that reduce driving demands. The results from Richard et al.’s analysis (when drivers’ bottlenecks occur and thereby give a potential accident situation) comport with conducted crash analyses. A summary of key information processing bottlenecks in each task from the task analysis (see table 7) is given below.

Approach
Difficulties when approaching an intersection include moderate visual demands arising from information acquisition requirements, such as identifying intersections characteristics, understanding signs, determining if the traffic light is about to change and identifying an unfamiliar intersection as the turn intersection. Richard et al. (2006) identifies the last demand as a potential problem. A street sign must be read in time so that he driver will be able to decelerate safely, but the street sign does not become readable until the driver is close to the intersection. If long time is needed to complete this task, it affects a safely braking and implies less time completing other tasks, for example looking for hazards.

Enter correct lane
Entering a correct lane is time limited and causes some drivers to compromise mirrors and shoulder checking when changing lane. Something that complicates the lane-change manoeuvre is the need to accommodate the changing speed of vehicles in the destination lanes. One way to address safety issues for this task is to give information that could be used to initiate a lane change sooner in the approach. This would give drivers more time to execute the manoeuvre. (Richard et al., 2006)

Decelerate/stop
The task decelerate/stop do not imply high workload for drivers. There are however times when drivers have to face a high number of concurrent tasks. Drivers have to safely decelerate, maintain appropriate spacing from other vehicles and observe status of lights. In complex situations these visual and cognitive subtasks can interfere with the ability to discover and react to hazards. (Richard et al., 2006)

Decision to proceed
In the next stage drivers have to make different key judgements whether or not it is safe to proceed under a short period of time. In complex situations, important decision-making takes longer than the time available to stop and proceed safely. (Richard et al., 2006)

Intersection entry
Difficulties in intersection entry are associated with drivers having to check for hazards at various locations. This is especially a problem when turning without first making a complete stop. In this case, drivers have to check for vehicles and vulnerable road users in the turning path under a short period of time, since the car is quickly approaching the turn location. Furthermore, the tasks draw on the same information processing resources. (Richard et al., 2006)

Prepare for turn/proceed
The primary difficulties in this, sometime high-stress, situation is the gap-judgement task that is combined with having to look for other hazards. The consequence of making an error in judging the gap could be a collision with a fast-moving vehicle and the task is therefore apprehended as high-stressed. (Richard et al., 2006)

Execute turn/proceed through intersection
The process of turning could be associated with high workload demands in a potential high-stress situation. Tasks include precise manoeuvres and looking for hazards. This has to be done while quickly accelerating and adjusting velocity to traffic. (Richard et al., 2006)

4.2.2 What to include in the intersection system output

Making it easier for drivers to perform the difficult tasks is the key to reduce accidents or near-to-accidents. To be able do this, it is important to reduce the workload demands (identified in chapter 4.2.1) by providing information and notification.

For some bottlenecks, supporting and warning systems already exist and these bottlenecks are therefore not taken under consideration when developing an intersection support and warning system. Some difficulties regarding entering correct lane and decelerate/stop are for example supported by the blind spot information system (BLIS) and the adaptive cruise control (ACC) with Distance Alert. BLIS alerts the driver when a vehicle enters the driver's blind spot and ACC automatically adapts the speed (at speeds over 30 km/h) so that a minimum gap to a vehicle in front is held. If the driver is too close to a vehicle, when ACC is disengaged, the Distance Alert gives a warning message (a red light in the lower section of the windscreen). Furthermore, the collision warning supports the driver if a crash is likely to happen. Richard et al. (2006) also identified determining an unfamiliar intersection as the turn intersection, as a potential problem. This is however not a dilemma if the driver uses a navigation system, guiding him/her from one location to another.

For other bottlenecks an intersection system could be of use. To be able to know what to include in such a system, a list of potential countermeasures from the information processing and crash data analyses was generated. It consists of issues that could be used in a new information system that supports the driver to safely navigate an intersection.

- Providing information about the intersection. Including facilitating when to initiate a lane change, the detection of signs and signals and showing information of the timing of the lights.
- Providing notification on potential hazards; detection/attention of vehicles and vulnerable road users.
- Providing information that helps with judging presence and safety of gaps.

Providing the driver with the above information is as a precaution, making it easier for drivers to perform their tasks. It is however important to realise that even though the driver is provided with the information he/she could still be overloaded with demands, other road users could do something unexpected or they could for some other reason get into a time critical situation. The system has to be able to support this as well. Therefore, warnings if the drivers get to close to an object or are about to break rules are of great importance. The intersection system could thus be subdivided into two fundamental categories:

1) An information system that supports the driver by giving:
    - information about an upcoming intersection
    - information to notify the driver about other road users
    - information that helps the driver with gap judgements

2) A collision avoidance system that warns the driver:
    - when getting too close to another road user
    - when breaking regulations

5 User requirements

The chapter starts with a specification of requirements important to gain system usability and driver safety. Then a summary is given of results from two intersection support studies in Europe and from the interviews conducted within this thesis. The interview study contributed to the understanding of system output, what drivers would like to receive from a support and warning system.

5.1 Usability requirement specification

The intersection system should be assisting the driver in problematic situations and contribute to an improved driving behaviour. It must not pose an extra workload or distract the driver's attention from the driving task or the surrounding traffic. In order to be able to gain system usability and driver safety, lists of requirements (see table 8 and 9) were derived from the guidelines in chapter 2.2. A system's usability is for example dependant on the possibility to understand the system output, the effectiveness of the system (the ability of drivers to complete tasks using the system) and users' acceptance.

DRIVER SAFETY
1. The system must not distract the driver from the driving task
2. The system must avoid overloading the driver
3. Glances time off road to be able to perceive visual information must be minimised
4. Stress-factors caused by the system should be non-existent
5. When multiple warnings are detected at the same time, the system must prioritise the information that has the highest safety relevance
6. The system should be able to detect when the driver is in a critical situation and adapt the information flow, e.g. interact with IDIS
7. The system must not promote risk taking by the driver
8. The system must not cause other collisions to occur

Table 8: List of requirements for gaining driver safety

SYSTEM USABILITY
Understanding
1. Information must be understood (e.g. the meaning and severity) 1.1 The system must be easily understandable for all drivers, e.g. for those with impaired hearing as well as those who have the defect colour-blindness 1.2 The system must speak the user’s language, e.g. by using familiar terminology 2. The information must be clearly conspicuous and easy to perceive under all driving conditions, e.g. in any weather, light and sound condition 2.1 A complex system should be avoided 2.2 Information must be clear to avoid driver confusion 3. The driver must be able to easy determine the state of the system (if the system is on or not) 4. Warnings should be distinguishable and not confused with other types of warnings in the vehicle
Effectiveness
5. If the system is deactivated, activation of the system should be easily made 6. The system must make the driving task easier 7. The system should be easy to learn 8. Warnings must be noticed 8.1 Imminent stimuli should be distinct and easy to discriminate 9. Warnings must be perceived (read/heard) 9.1 Visual information that seeks the driver’s attention should be placed close to the driver’s line of sight, but no part of the system must obstruct the driver’s view of the road 9.2 A critical message should take over the rest of the information given in a vehicle, e.g. a visual message should take over part of the display and conflicting auditory signals should be reduced in volume during the presentation of a auditory message 10. The system must be intuitive 10.1 Drivers must be able to immediate understand the consequence of a warning 10.2 The information must be quickly understandable during stressful situations, since negotiating an intersection requires drivers to make responses on emerging conditions under time pressure 10.3 Critical warnings must elicit an automatic or conditioned response 10.4 Warnings must be compatible with driver’s response 11. Warnings should focus the driver’s attention to the hazard
Acceptance
12. The system must not contain factors of irritation 12.1 The driver should be able to modify the intensity (brightness) or volume of the alert 12.2 Sensitivity settings should be provided to modify the timing of warnings according to driver preference 13. The system should not embarrass the driver 14. Drivers must be able to trust the system 14.1 False and nuisance alarms must be minimised 14.2 Warnings must not be given too late or too early 14.3 Warnings should not be given before the moment the driver would normally react, steering away, releasing the accelerator, or braking 14.4 The interface should create confidence in the system 15. Drivers must be satisfied with using the system 16. Drivers must feel in control

Table 9: List of requirements for gaining system usability

5.2 Drivers' opinions about system output

To be able to get insight into users' requests on the intersection system output, results from two different European projects were summarised. These projects are interesting since their aim to reduce collisions at intersections, is similar to the aim of the intersection system developed by Autoliv, VCC and Chalmers University of technology. Indications on users' requests were also gained from eight structured interviews within this thesis. Before the results are presented a short description of the European projects are given.

A project named INTERSAFE aimed to develop an intersection driver system to improve safety and to reduce fatal collisions between vehicles at intersections. The project was mainly focused on stop sign/traffic light assistance, right-of-way assistance (warns if the driver or other road users seems to violate a right-of-way) and turning assistance (helps with finding a good gap). During the project user requirements were identified and evaluations of concepts in driving simulators and demonstrator vehicles were made. (Fuerstenberg, Hopstock, Obojski, Rössler, Chen, Deutschle, Benson, Weingart, Manrique de Lara, 2007)

An ongoing project, WATCH-OVER, aims at developing a system that can help drivers avoiding road accidents that involve vulnerable road users. This is done by real-time detection of pedestrians and bicyclists equipped with a special module that can be integrated into wearable objects, like watches, shoes or consumer electronics. User requirements, on when to give information/warnings and how to give it, were identified through 154 completed questionnaires with drivers from 10 different countries. (Andreone, Bekiaris, Guarise, Mousadakou, 2006)

5.2.1 Information about an upcoming intersection

Requests on output from the interview study

Information about an upcoming intersection refers to getting information about the type of intersection, traffic signs and traffic signals. Results from the interviews show that almost everyone (six of eight) would like to receive information (type and distance) about an upcoming intersection, to be able to plan their driving. The respondents thought it would be especially good if they were driving in a, to them, unknown area.

Only two of eight respondents wanted to get information about traffic signs. The ones not interested in such information thought that they were able to see the signs for them self and were worried about getting to much information. One respondent would not like to have information about a traffic sign in advance, but rather a possibility to get information about the last sign passed. Furthermore, information about rules applicable on a whole stretch (for example major road or right-of-way) could be given. This is especially good if the driver has missed a sign or is uncertain for some other reason.

The interview study also indicated that drivers did not think that speed recommendations or continuous information about state of traffic lights is necessary, especially not from a safety point of view.

Results from other studies

An experimental study made at the University of Calgary showed an improvement of intersection behaviour for those of age18 to 24 and 65+ when they got advanced in-vehicle signs presented on a HUD. An in-vehicle sign, alerting drivers to upcoming traffic light changes, increased the stopping behaviour at intersections with relatively short onsets. Results also showed that the advance sign may decrease drivers need to look at the traffic lights as frequently. The reductions in scanning may however also indicate a carryover from looking at the HUD. The latter is not necessarily a positive benefit. (Chisholm, Caird, Lockhart, Vacha, Edwards, 2005)

5.2.2 Information to notify the driver about other road users

Requests on output from the interview study

Whether to receive information about vulnerable road users or not, six of eight interview respondents were negative. They were worried about getting too much information and thought that such information would disturb their attention on the surroundings. When approaching an intersection they would like to focus on their task and not receiving unnecessary information. The respondents thought however that there are situations when such information could be very helpful. For example in areas not familiar to the driver and also in case of the driver having a visual obstruction or reduced visibility. When discussing an option to receive information on explicit demand, for example by pressing a button on the steering wheel when they feel in need of the information, all of them were however positive. This as long as they did not get all information available in an intersection, but only information possible to indicate a risk.

Furthermore, respondents were asked what type of information they would like to get about the vulnerable road users. The presence of a VRU was perceived to be the most important information, followed by location and heading of the VRU. A few would like to know the distance. In addition seven of eight respondents thought that it is enough to know that it is a vulnerable road user. One respondent thought however that it would be good to know if it is a pedestrian or a bicyclist and perhaps also if it is a child.

The interviews conducted within this thesis also resulted in indications whether or not drivers would like to be informed about the presence of other vehicles if there is no accident risk. The opinions and arguments were the same as when asking about vulnerable road users. The respondents did not like to get too much information and thought they were able to see other vehicles for them self. Although, it could be good to receive information regarding vehicles possible to be a risk on explicit demand. For example if sight were masked or reduced. One respondent thought that information about other vehicles would be less meaningful if the intersection was controlled by traffic lights.

If information about other vehicles were presented, they would like to know the location of the vehicles. Distance and maybe speed (or if the vehicle is moving or stationary) were also considered to be helpful. In addition two of the respondents would like to know if a vehicle is an emergency vehicle.

Results from other studies
Results from the WATCH-OVER study are in some aspects in accordance with the interview study conducted within this thesis. The majority of the WATCH-OVER respondents would not like to be informed about the presence of a vulnerable road user if there is no accident risk. The respondents that stated that they would like to be informed, would prefer to know the distance and maybe also the heading of the VRU. (Andreone et al., 2006)

When Andreone et al. (2006) asked how the respondents would like to receive the above information the majority would prefer to be informed by an icon on a display. After that a tone/beep was most preferred, followed by spoken messages, light emitting diodes and a few respondents suggested the use of a map. If the information were going to be presented visually, the majority would prefer a head up display. On second place came the instrument cluster display and on third the centre stack display. (Andreone et al., 2006)

5.2.3 Information that helps the driver with gap judgements

Requests on output from the interview study
The respondents were furthermore asked if they would like to get information that could be helpful when judging gaps in oncoming and crossing traffic. A gap refers to the gap between the subject vehicle and the threat vehicle that will allow the completion of the subject vehicle's intersection traversal before the threat vehicle enters the intersection. If the threat vehicle and subject vehicle will, at the same time, occupy the same space in the intersection, it is an unsafe gap. (Pierowicz et al., 2000) Five respondents said that judging gaps is not a problem and that such information only would lead to an overload of information. However, if the possibility existed to receive such information on explicit demand, the majority (five of eight) thought it would be useful in situations of uncertainty.

Results from other studies
The INTERSAFE project has conducted driving tests on turning assistance that helps with finding a good gap and the test resulted in rather favourable results. The results also showed that the intersection assistant for a left turn was more useful than for lateral traffic and that it was more useful while starting from a complete stop. Most respondents felt that, for some situations, the system would lead to a strong increase of safety. Evaluations made after driving tests also indicated that information on a head up display is more preferred than on an instrument cluster display. (Fuerstenberg et al., 2007)

The INTERSAFE system also includes an autonomous inference. If the driver has stopped, looking for a sufficient gap, or he/she is about to turn and a critical situations appear, the vehicle will ignore the driver's attempt to accelerate (can be overridden with a kick-down) or will autonomously brake. A system reaction will only appear if the risk level is high. However, through evaluations, problems with acceptance of system reaction were identified. The system reaction was valued inappropriate if gap was judged too small and the autonomous system did not prevent the driver and also when gap was judged large enough and the system stopped the driver. This situation was likely to occur, due to differences between the way the system judges gaps and the way drivers do. The system had a fixed criterion, dangerous gap size, but drivers' gap acceptance size depends on several factors, which is hard to predict. (Fuerstenberg et al., 2007)

5.2.4 Collision avoidance

Requests on output from the interview study
In case of accident risk all respondents from the interviews would like to receive warnings if they are about to violate signs or signals. In addition they would like to get warnings about possible accidents with vehicles or VRUs.

One respondent from the interview study thought it would be very good if the car also could give support on how to adopt a more safety driving style, a sort of driving school. When a trip is completed a driver could be able to get a driving review, showing unsafe situations, why they became unsafe and tips on how the driver could improve the driving style to a safer level.

Results from other studies
Results from the WATCH-OVER study also show a positive attitude towards warnings. The great majority would namely like to receive a VRU warning, preferably as a tone/beep or as an icon on a display. Other warning suggestions were spoken messages, light emitting diodes, the use of a map and vibrations on the seat. (Andreone et al., 2006)

Andreone et al., (2006) also identified different support levels for different particularly dangerous scenarios, in which the system is considered valuable. More support is for example needed from the system when pedestrians are involved and less when there are bicyclists. Circumstances under which the support would be preferred were also investigated. The conclusions were that all day times are important and that weather conditions with rain and fog should be considered as the most important. In case of daytime, fine weather should however not be neglected. (Andreone et al., 2006)

6 Design process

This chapter presents the result from the design process. First the scenarios that served as a base for the development of the concepts are described. Chapter 6.2 consists of a discussion of decisions that had to be made in order to generate design ideas for an information system that support the driver when negotiating an intersection. This subchapter is finished off by a description of the final concepts that were evaluated. Chapter 6.3 has the same structure, but refers to the collision avoidance system.

6.1 Choice of scenarios

To be able to generate concrete concepts driver scenarios were generated. The scenarios describe problematic situations for the drivers, where an intersection system could be of good use. The following list describes factors used when selecting two scenarios to base the concepts on; one scenario for an information system that supports the driver when negotiating an intersection and one for a collision avoidance system that warns the driver. Concepts were then generated for each subgroup with regard to the belonging scenario.

- According to the interview study within this thesis, an information system is perceived as most valuable in areas not familiar to the driver and also in case of the driver having a visual obstruction or reduced visibility (see chapter 5.2.1 and 5.2.2).
- According to Richard et al. (2006) entering a correct lane could be a safety issue (see chapter 4.2.1).
- According to a study made by Vollrath and Schießl (2005) an intersection where information from multiple directions has to be processed and where more decision has to be made lead to larger subjective strain and wishes for assistance. (Vollrath & Schießl, 2005) Therefore one scenario included yielding and having to look left and right while turning left, as compared to driving straight through and having the right of way. Furthermore, results from the INTERSAFE project showed that the intersection assistant for a left turn was more useful than for lateral traffic and that it was more useful while starting from a complete stop (see chapter 5.2.3).
- According to the WATCH-OVER project a problematic situation is when a vehicle is turning left and pedestrians are crossing the lane from the right to the left. Another problematic situation appears when a bicyclist and a vehicle have perpendicular trajectories, and the bicyclist is crossing the vehicle’s road from the right. (Andreone et al., 2006)
- Habibovic (2007) has made a rough accident analysis based on accident data from Swedish, German and American accident database. Reports in the databases try to identify the most common accidents. One common accident scenario occurs when a vehicle is driving straight and a pedestrian is crossing the driver’s lane after the intersection. (Habibovic, 2007)

Figure 4a and 4b shows an illustration on the scenarios used when generating the concepts. The grey car is the subject vehicle and in figure 4a it is going to turn left and in 4b it is driving straight ahead. For the scenario description used during evaluations see appendix B.

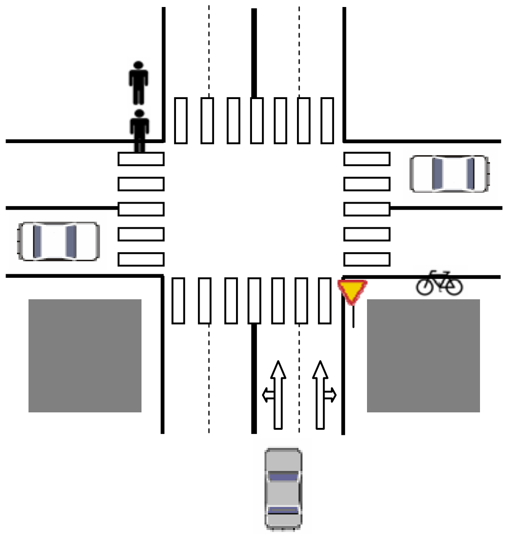


Figure 4a: Scenario for an information and support system

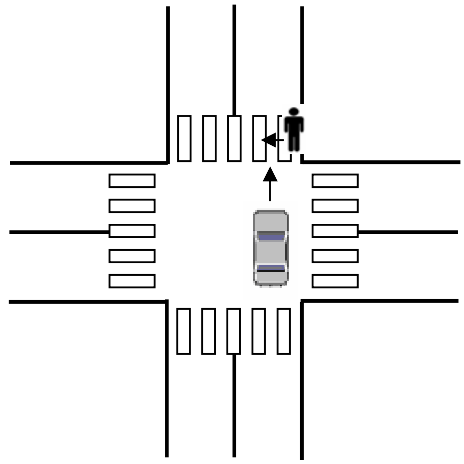


Figure 4b: Scenario for a warning system

6.2 Information and support system

In chapter 4.2.2 possible outputs for a new intersection support system was identified. It included facilitating when to initiate a lane change and to detect signs and signals, showing information of the timing of the lights, providing notification on potential hazards and providing information that helps with judging presence and safety of gaps. All of these outputs except one (the timing of traffic lights) were included in the final concepts. Even though some studies have shown an improvement of intersection behaviour when the drivers were alerted with upcoming traffic light changes (see chapter 5.2.1), the scenario chosen for this thesis did not include the possibility for having traffic lights. Furthermore, the interview study conducted within this thesis indicated that drivers did not think that continuous information about state of traffic lights is necessary, especially not from a safety point of view.

6.2.1 Design ideas

6.2.1.1 Selecting message modality & style

When deciding what modality to use for supporting information the potential of driver annoyance is very important. This because intersection information is likely to occur often. Auditory signals and tactile displays should for example not be used due to the potential of becoming annoying (see table 2 on page 8). Furthermore a tone should be reserved for ICW only to keep the high level of urgency associated to the signal (see chapter 2.2.6.4). The effectiveness of a speech message could be dependent on what type of information it conveys. It is important that a driver could distinguish between different information systems in the vehicle and if a voice is saying “pedestrian to the right” it might potentially be confused with the navigation system saying “turn right”, especially in a noisy environment where the message not clearly can be detected. Even though it is possible to say “pedestrian nearby” it is not included in the concepts. This since both the WATCH-OVER study and the interviews conducted within this thesis indicated that drivers prefer to receive more information than that there is a VRU present (see chapter 5.2.2). This leads to the use of a visual display for supporting information.

There is also a possibility to integrate an autonomous inference like the one in the INTERSAFE system (see chapter 5.2.3). In that system the vehicle ignore the driver’s attempt to accelerate or will autonomously brake, if the driver are looking for a sufficient gap and a too small gap, according to the system, appear. Results showed that such system was often valued as inappropriate due to differences between the way the system judge gaps and the way drivers do. That kind of system was consequently not recommended for this intersection system.

As described in chapter 2.2.6.1 there are different types of message, notification messages and command messages. All concepts were developed with regard to the first message type, advising the driver of a situation but leaving him/her to both interpret the situation and decide how to respond to it. This because commands have the potential of misdirecting the driver if the system fails to consider all relevant factors.

6.2.1.2 Selecting message location

Resources available for visual information are displays located on the windscreen (HUD), behind the steering wheel (the instrument cluster display) and on top of the centre stack (centre stack display). Furthermore, light-emitting diodes showing lights on the windscreen (LED), or lights to the left and right near the door mirrors could be used.

Regarding the physical grouping of displays Lee et al. (1999) discussed a centralized approach versus a distributed one. Display location can act as a code to identify the urgency or type of the information and can be used when messages can be divided into a number of meaningful categories (see chapter 2.2.5.1). As derived in chapter 4.2.2 messages provided from the intersection support system can be divided into the categories: Information about an upcoming intersection, Information to notify the driver about other road users and Information that helps the driver with gap judgements a distributed approach could be used.

Since the information and support system provides the driver with messages that are important when guiding the driver from one location to another, the messages could be seen as belonging to the category of navigation information. This kind of information is presented on the centre stack display or on the HUD (see chapter 4.1). Therefore concepts at these two locations were generated. The advantage of placing information on the centre stack display is the possibility to provide more information. This since the display is bigger and do not cover the driver’s line of sight. Furthermore, it is the driver’s choice when to look at such information since he/she has to consciously turn the gaze towards the display. It is however important to consider that a driver’s eyes are less likely to be directed into the vehicle in intersections.

Regarding information that helps the driver with judging presence and safety of gaps, results from the INTERSAFE project showed that drivers prefer to get such information presented on a HUD. Gap support concepts placed at the centre stack display were therefore not included.

The intersection support system will for example inform the driver of other road users. According to interviews within this thesis this information should include a directional cue (see chapter 5.2.2). One way of providing the driver with a notification in what direction to be extra attentive is to use the light emitting diodes, either on the LED or near the door mirrors. The diodes could be seen as a small indicator on where to look, to the left or to the right. Intersection information is however likely to occur often and could therefore potentially take the importance of the lights (when they are used in the blind spot information system or in the collision warning system) away. Furthermore, using the diodes for the intersection system could lead to a potential confusion risk. If the diodes near the door mirrors are used, the driver might not know if to check the mirrors for upcoming vehicles and thereby not change lane or whether to be extra attentive for road users in that direction. The use of light emitting diodes was therefore not included in the concepts.

Finally it is important to realise that sometimes a prioritisation of in-vehicle messages from different systems in the car need to be done. As mentioned in chapter 2.2.4, Campbell et al. (2007) recommend using the ISO 16951 for the prioritisation.

6.2.2 Final concepts

This chapter describes the final concepts that were evaluated with active drivers. Since the scenario to base the concepts on is occurring in an, to the driver, unfamiliar area, it is assumed that he/she uses a navigation system. All concepts are therefore developed from the view that the information and support system is integrated with the navigation system.

Information about an upcoming intersection (system A)
200 meters before a driver reaches an intersection, it is possible to get up-to-date information from the sensors within the intersection. The goal with this subsystem is to inform the driver about the characteristics of the intersection in order to facilitate their driving plan. Since this system is integrated with the navigation system, a turn-by-turn navigation symbol will appear on the HUD showing distance to turn. To this symbol one additional symbol was added, the intersection type (e.g. four legged, three legged etc), see concept A1 in figure 5. During the idea generation concepts showing even more information were developed, but due to the delimited size available when showing symbols on the HUD, they were considered to messy.

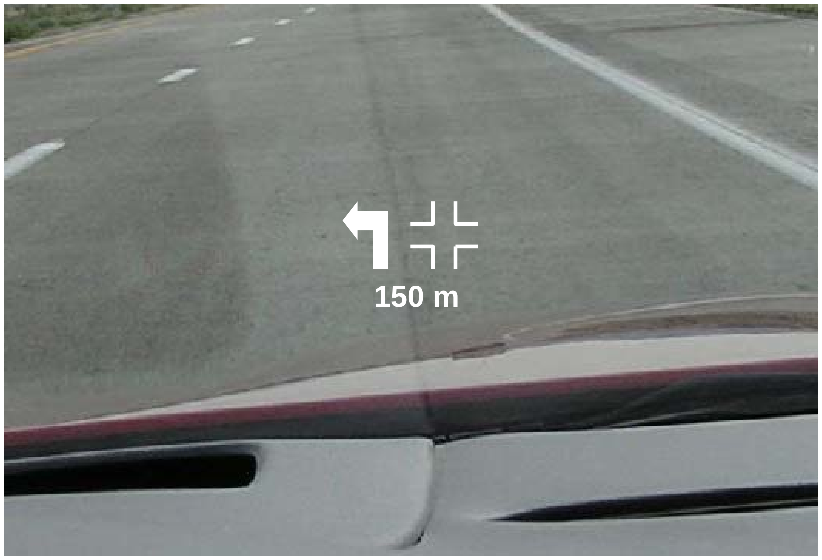


Figure 5: Concept A1 - Intersection type shown on the HUD.

The size of the centre stack display is however bigger and therefore concept A2 do not only include the intersection type, but also information that could facilitate entering a correct lane and detect signs and signals (see figure 6). The concept shows the number of traffic lanes, directions of traffic lanes and regulations that concern the driver (e.g. stop-sign, right-of-way-sign or traffic lights). Since this system is integrated with the navigation system, a recommended traffic lane for the planned journey is shown with yellow colour. The intersection information will take half the place on the centre stack display, where the other part is still showing the map with information from the navigation system. The map image in the concepts does however not show a correct information, seeing that it is does not show the zoomed view used when driving in an urban area.

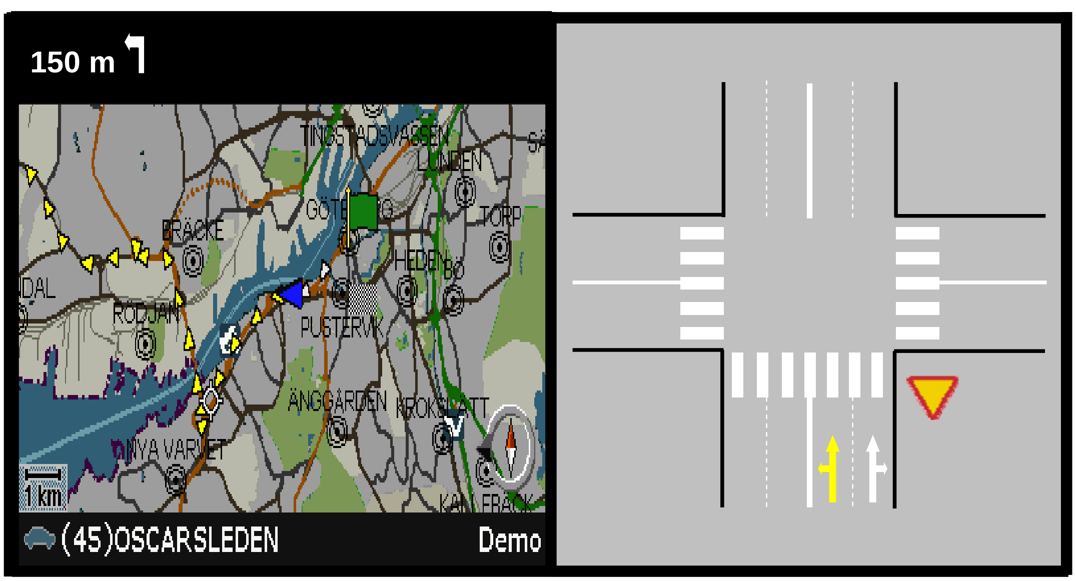


Figure 6: Concept A2 - Intersection type and information that could facilitate entering a correct lane and detect signs shown on the centre stack display.

Information to notify the driver about other road users (system B)
200 meters in front of an intersection it is also possible to get information about other road users in the intersection. The goal with this subsystem is to provide the driver with a notification of where to be extra attentive. Since information about the intersection will change over time until the driver has driven trough it, all icons should be possible to update while still keeping the intersection map.

In concept B1 the same intersection symbol as in concept A1 is used, although it is enlarged (see figure 7). Dots are showing areas where road users are present (there is thus not one dot for each road user). The dots look the same whether it is a vehicle, bicyclist or pedestrian.

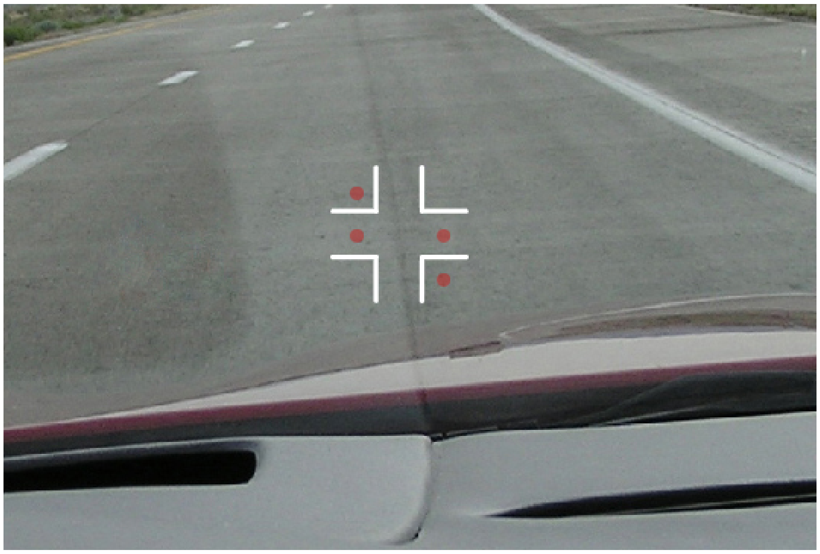


Figure 7: Concept B1 - Areas where road users are present shown on the HUD.

In concept B2 it is possible to get information about the type of road users (see figure 8). Again, there will not be one symbol for each road users. If there is more than one object on a segment, the object that has the highest priority will be shown. The prioritisation should be based on the risk level for a collision, including for example distance and speed of the object.

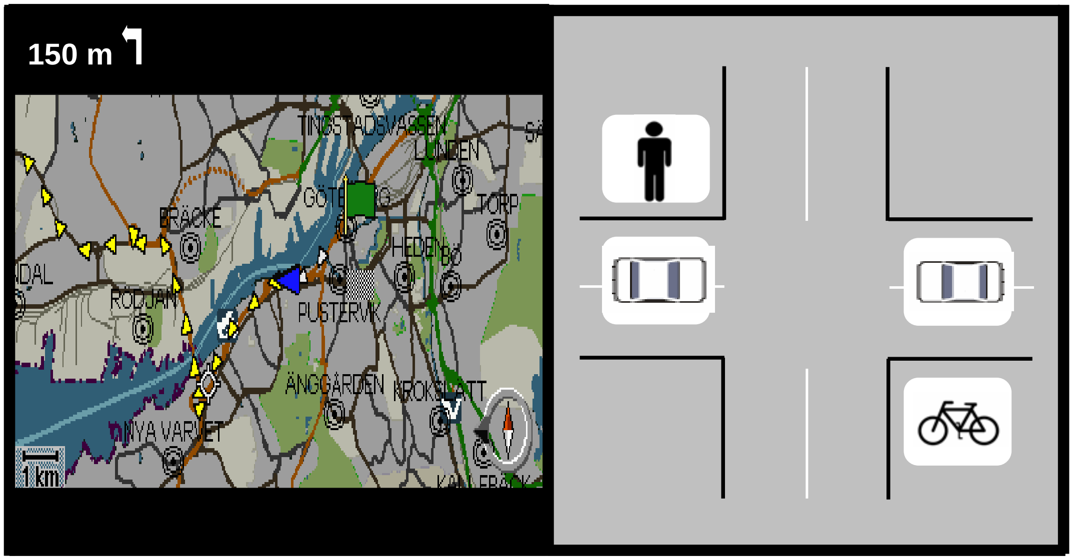


Figure 8: Concept B2 - Type and location of present road users shown on the centre stack display.

If the driver would like to receive information about both road users and the type of an intersection, figure 9 below shows a combined concept of A2 and B2.

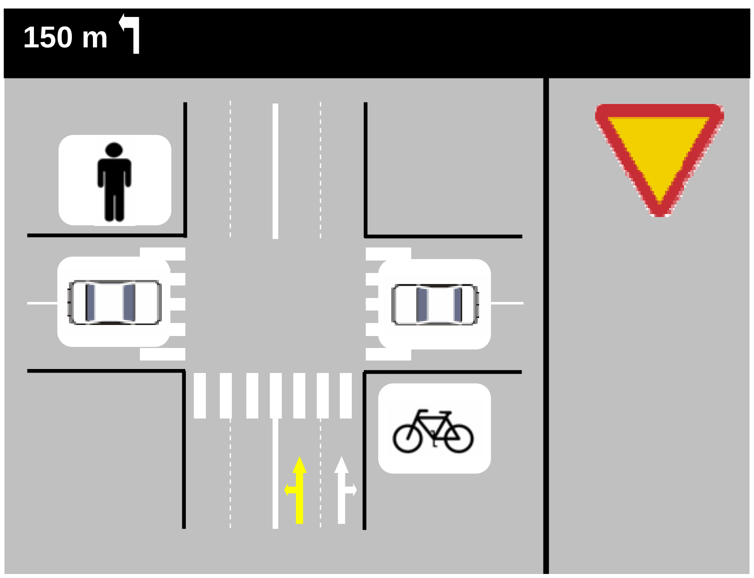


Figure 9: Combination of concept A2 and B2 - Information about an intersection and about other road users.

The respondents from the interview study pointed out the importance of prioritising the information available in an intersection. Drivers are only interested in information possible to be a risk. A suggestion is therefore to derive areas of interest for the driver. The size of the areas should be dependent on the speed of the subject vehicle, intended manoeuvre and speed of road user. Figure 10 is showing a rough example of interesting areas when driving straight ahead. If the driver intends to make a left turn (possible to determine through input from the turning indicator) the areas will be shifted towards the left. All road users in the area of interest are however not interesting, for example vehicles that are on their way out of the intersection. They can not be seen as being a risk to the driver.

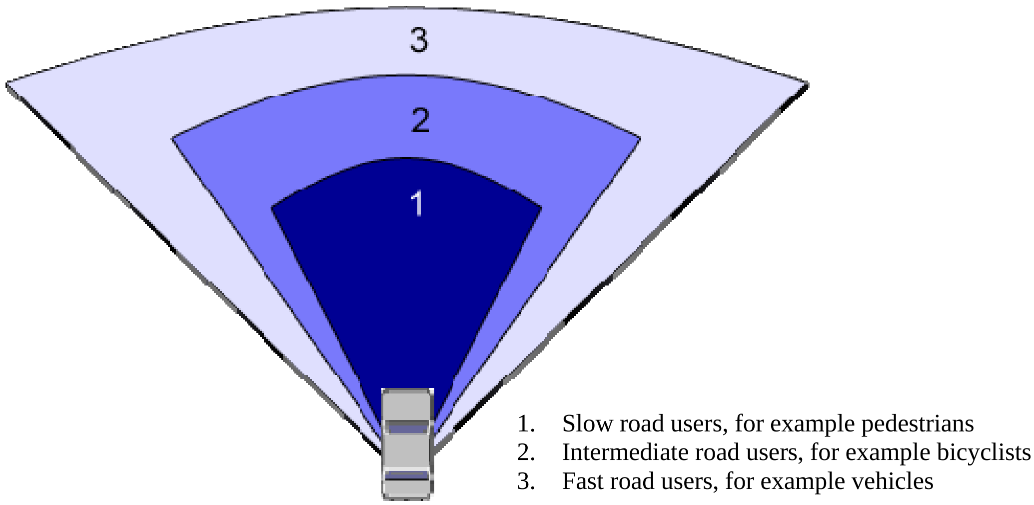


Figure 10: Illustration of potential areas of interest for a driver driving straight ahead

Information that helps the driver with gap judgements (system C)
The concept on gap judgements will appear in the driver's line of sight when the driver is standing still at the intersection. At this time it is no longer important to get information about the type of an intersection. The concepts are integrated with the turn-by-turn navigation on the HUD. This since gap acceptance is judged differently when turning to the left, to the right, or driving straight forward. Furthermore, the safety level of a gap has to be continuously estimated. It should also consider the status of the traffic lights and if possible both considerate vehicles and vulnerable road users. Since it is natural for drivers to accept different gap sizes depending on the situation and the intersection characteristics (for example number of lanes), the support system should be tailored to each intersection's peculiarities, in the same way that the drivers adjust their gap acceptance.

The concepts are notification messages which never instruct a driver to make a turn at a particularly time, but rather advise the driver of different safety levels. In this way, the decision to turn remains with the driver (as does the associated liability in the event that a crash occurs) and the driver can take own driving skills into account.

In the first concept, C1, the colour of the arrow changes with regard to different safety levels. From the default colour of the turn-by-turn navigation to yellow, to orange and finally red, as the margin of safety decreases (see figure 11). In the second concept, C2, a bar is instead indicating a rising or falling risk (see figure 12).

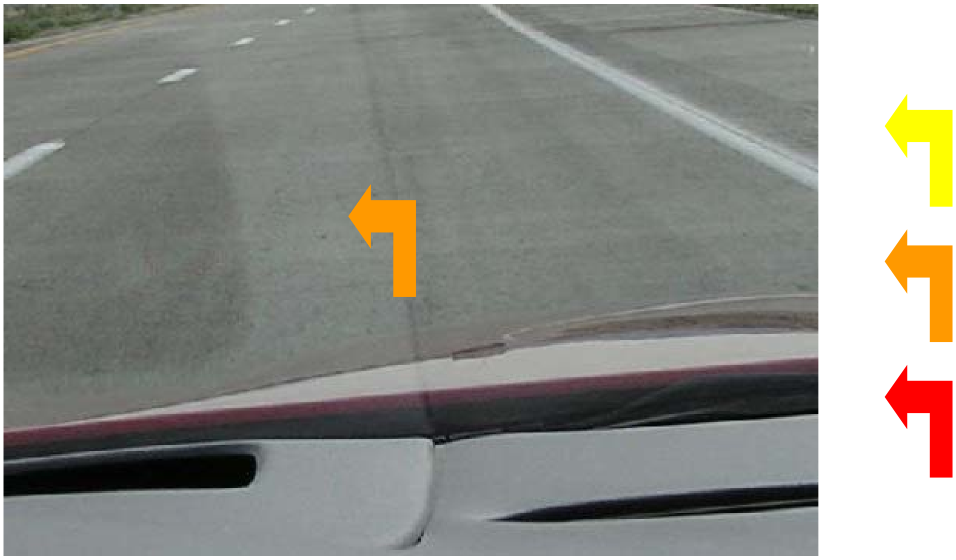


Figure 11: Concept C1 - Different gap safety levels displayed as changing arrow colours on the HUD.

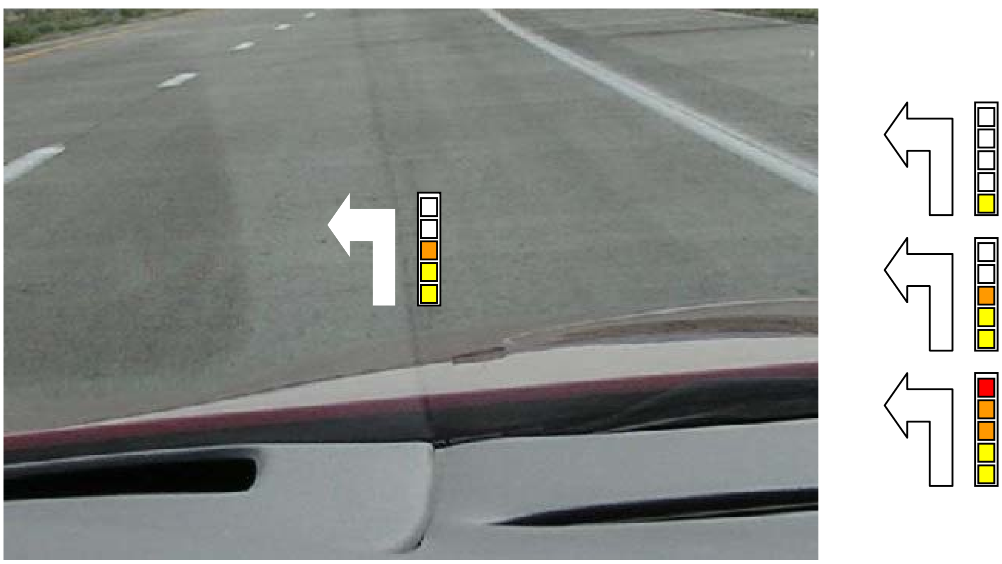


Figure 12: Concept C2 - Different gap safety levels displayed as a scale on the HUD.

6.3 Collision avoidance system

As derived in chapter 4.2.2, a collision avoidance system refers to warnings given to drivers if they get to close to an object or are about to break rules. Due to trying to keep the number of concepts to evaluate down, the scenario for a warning system did only include another road user. Warning concepts for breaking regulations were therefore excluded in this thesis, but are still interesting to investigate further.

6.3.1 Design ideas

6.3.1.1 Selecting modality

The following aspects from the list of usability requirements (see table 9) describe the design criteria used when selecting warning modality. Warnings must/should:

- Be easily understandable for all drivers, e.g. for those with impaired hearing as well as those who has the defect colour-blindness
- Be perceived
- Focus the driver's attention to the hazard
- Be compatible with driver's response

Dewar & Ohlson (2007), like that of many others, recommend using at least dual modality for imminent warnings. A multi-modal driver-vehicle interface is recommended even here, since no single modality meets all design criteria and multi-modal signals provide greater opportunities for drivers to detect the warning signal. As summarised in table 2, visual warnings enables more detailed information, but requires drivers' attention to be on the forward view to perceive the warning. Mere visual information may therefore not be noticed in time and might possible decrease safety due to its potential distraction effect. Auditory warnings exclude hearing-impaired drivers and can be masked by noise. They can also potentially be considered annoying. Tactile warnings on the other hand are discrete, personal and notable even in noisy environment and if the driver's attention is not directed to the visual display. Many tactile displays do however not reliably prompt appropriate responses.

As derived in table 5, steering wheel vibrations, steering wheel torque and seat vibrations do not have the natural mapping to braking response. In addition, accelerator counterforce and vibration require that the driver always is in contact with the tactile feedback source. This cannot be guaranteed (for example if the driver uses a cruise control). Furthermore, if the gas pedal vibrates as a collision warning, the wanted driver behaviour is to lift the foot off the pedal. If the vehicle also has ABS in which the brake pedal vibrates when the system engages, the driver is supposed to press down hard on the pedal. In one situation the vibration tells the driver to lift up the foot, in the other to press down. This could lead to a confusion of which pedal is being used and what the proper response is. Another tactile display type, brake pulsing, is though promising for urgent information due to low attention demand and mapping to a break response. There are however for now insufficient data to claim that brake pulsing ICWs are equally effective as auditory ICWs. Furthermore little investigations has been made on the potential loss of vehicle control on slippery surfaces and brake pulsing do not induce an orienting response. Until further research validates that tactile warnings are as beneficial to driver reaction performance as auditory warnings, a combination of auditory and visual message is to recommend.

The auditory signal should be considered as the primary warning modality, since getting drivers attention is critical. The visual display serves as a backup and a supplement if the auditory signal is masked by in-vehicle noise or for drivers with hearing impairments. A critical message must be detected and not disappear in the rest of the information given in a vehicle. A visual message should therefore take over part of the display when it appears and conflicting auditory signals should be reduced in volume during the presentation of a critical auditory message.

When deciding what auditory signal to use, table 4 was consulted. When using auditory signals for imminent crash warnings a speech message could not be recommended. Speech messages produce longer response times and there is some evidence that false alarms presented via speech displays are associated with greater levels of driver annoyance. When choosing between a tone and an auditory icon the type of icon has to be considered. An auditory icon is more easily learned and reduces the driver's reaction time but has to be compatible with a desired driver response. Icons conducting a braking response could for example be a car horn or a skidding tire sound. These sounds might however be confused with naturally occurring sounds (a real horn outside the car) and thereby leading to the driver ignoring the warning. Even though auditory icons seem to have a great potential, there is not sufficient data on auditory icons as imminent crash warnings. Until further research has been made, warning tones are consequently used for imminent warnings.

6.3.1.2 Selecting message location

As mentioned in chapter 6.2.1.2, resources available for visual information are the HUD, the instrument cluster display and on the centre stack display. Furthermore light-emitting diodes showing lights on the windscreen (LED), or lights to the left and right near the door mirrors could be used.

When providing visual warnings, they must be seen by the driver and if possible minimise in-vehicle glances. This because glances off-road are highly tied to crashes. Warning information should therefore be placed close to the driver's line of sight. The display that best meets these demands is the head up display and it should therefore be used for presenting the visual warnings.

It could be possible to use the lights to the left and right near the door mirrors to show the location of a hazard. These lights are already used in the blind spot information system. The desired response from such alert is to maintain the same lane and check the mirrors for upcoming vehicles. Most intersection accidents are however not due to vehicles coming up behind. The desired response from the intersection warning system is both perceptual, looking into the direction of the hazard, and motor, braking or turning away from the hazard. The use of diodes positioned near the mirrors for the intersection system could therefore lead to a potential confusion risk, not knowing what the desired response is. It is consequently not to recommend.

In present Volvo cars, a light emitting diode ramp is used for collision warnings with vehicles in front. The flashing red warning light connotes "stop" and could thus be used for all collision warnings indicating a braking manoeuvre.

6.3.1.3 Selecting number of warning stages

The choice of number of warnings should reflect the specific goals, capabilities and limitations of the system. One-stage warnings are more resistance to annoyance and distraction since they occur rarely. Furthermore one-stage warnings should be used if the rate of false alarms associated with a multi-stage system significantly reduces drivers' trust in the system. This since multi-stages may increase the likelihood of nuisance and false alarms (see chapter 2.2.2).

There are some difficulties in creating a reliable intersection system that has to be taken under consideration. The behaviour of vulnerable road users is hard to predict with high certainty. They can stop and change directions easily. It is however possible to get more reliable detailed information regarding other vehicles, since they do not have that many alternatives on the continuing route. This results in the possibility of high false warning rates for VRUs. A balance between generally valid warnings and too many warnings that is either false or perceived as unnecessary has to be made. Not being able to reliable warn for VRUs indicates the use of a one-stage warning. The use of a one-stage warning requires an immediate corrective action such as braking or turning away from the hazard. This implies the use of icons easily interpreted and therefore modifications of existing and tested icons were made.

6.3.1.4 Automated system

There is a possibility to integrate an automated system, working with the driver to execute successful manoeuvres and taking over control in emergency situations where the driver is unable to respond. Examples of such systems are the auto brake in Volvo's Collision warnings and the City safety system described in chapter 4.1. Active brakes give access to pre-charge the brakes and prepare for panic brake application. In case of the driver not reacting to a warning and a collision is imminent, the brakes will activate automatically. The city safety system automatically brakes the car if a collision is imminent when driving at low speeds. These two systems could cooperate with the intersection warning system.

The brake prepare should occur when imminent crash warnings are initiated, since such warnings requires a fast braking. The city safety system is very useful since the behaviour of vulnerable road users are not easy to predict. This gives the opportunity to reduce the severity of crashes, either if the system detects an imminent collision risk but there is not enough time to warn the driver or if the driver has missed or ignored a warning. When driving in higher speed automatically braking could occur as it does in the existing collision warning of present Volvo cars.

6.3.2 Final concepts

Collision avoidance system (system D)

All symbols used in the final concepts include an abrupt onset in the driver's line of sight, taking over all other information. Furthermore, information is redundantly coded across colour and size of symbol. Red colour indicates danger and large symbols indicate importance. As mentioned in chapter 2.2.6.2, red is not an intense colour for colour blind people. To catch their attention, a glaring yellow is best and this was taken under consideration in some of the concepts.

The information is also redundantly coded across different modalities. A warning sound from loudspeakers in the direction of the hazard induces an orienting response, as well as the message content from the suggested visual symbols. Except from a warning sound, all concepts also include the automated system described in chapter 6.3.1.4.

Concept D1 is a modification of the collision warning system within present Volvo cars. It includes a longer diode ramp and light will flash in the direction of the hazard. The left side of the ramp will be lightened and flash if the hazard comes from the left and the right side will be lightened if the hazard comes from the right. If the risk of collision is in front, the entire ramp will flash.

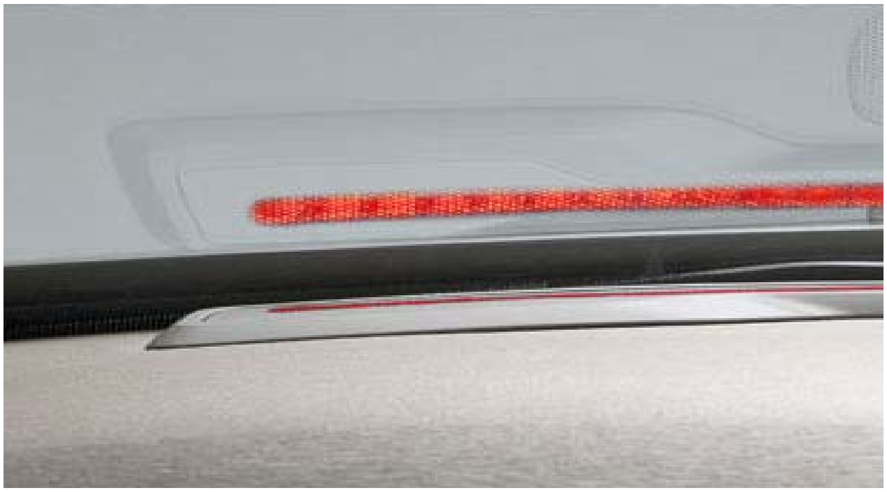


Figure 13: Visual concept for D1 - Red light flashing in the direction of the hazard.

Concept D2 is a modification of the ISO 2575 symbol for side obstacle warning (International Organization for standardization, 2004). The concept takes a car perspective, showing where on the car a crash is likely to occur (see figure 14). The concept is derived from a scenario where a risk of collision is in front. Images to the right show other possibilities, risk of collision with an object on the left or right side of the vehicle.

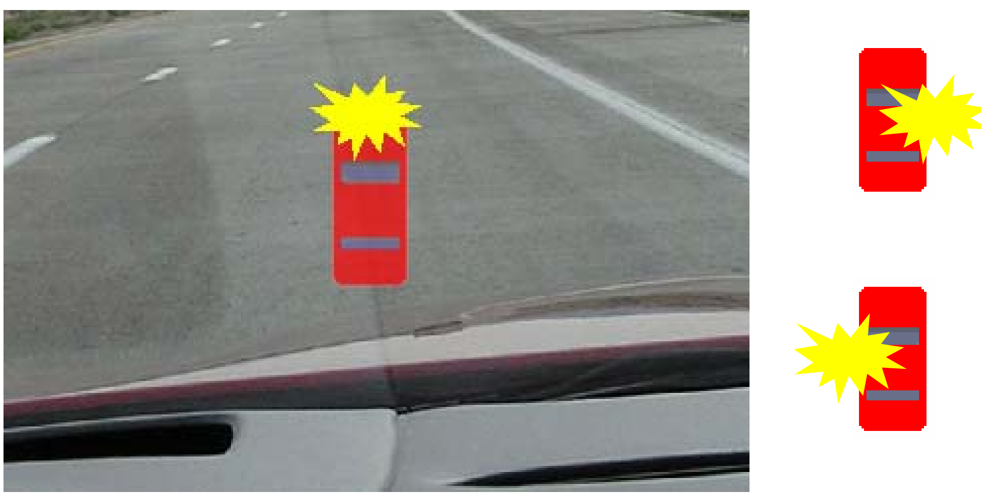


Figure 14: Visual concept for D2 - A car with a crash symbol indicating the direction of the hazard.

Concept D3 is adapted from a collision warning symbol used in a driving simulator test made in the INTERSAFE project. The concept shows the type of intersection and a star symbolising a crash (see figure 15). The star is shown in the area where the conflict object is coming from, in this case straightforward. Images to the right show alternative directions of the hazard; left or right.

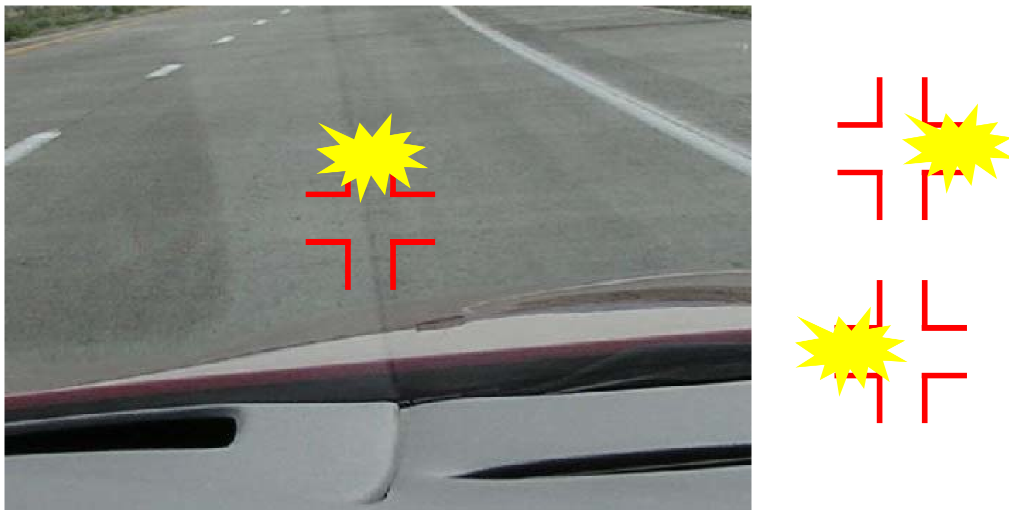


Figure 15: Visual concept for D3 - The type of the intersection with a crash symbol indicating the location of the hazard.

6.4 Recommendations for message timing

The question regarding how to calculate the risk level for an object and when messages should be presented to a driver is not worked out in this thesis. Important factors to considerate has however been identified during the thesis work.

When to initiate supporting information and warnings are critical to system trust, acceptance and effectiveness. The earlier the information is given, the less accurate the prediction could be, and thus the less relevant the warning will be to a receiver. This especially for VRUs, since their behaviour are hard to predict. A warning given too late is however also irrelevant, since that will not give the driver enough time to respond. Different studies suggesting trigger points have been mentioned in chapter 2.2.7.1 and could be seen as initial parameters to investigate further. For example it could be useful to include driver-vehicle input to determine the timing, since warnings may not produce the expected result if the driver is already in the process of taking appropriate action.

When deciding timing of warnings driver response time is of great importance. Attempting to determine a reasonable response time is complicated. Values are depending on the situation (for example the distance to an impending threat, type of threat, driving speed) and driver involved. Furthermore the time to respond depends on the intensity of the stimuli and the information required to process. It is therefore necessary to conduct driving tests in simulators with different traffic situations and traffic volume conditions with the chosen driver vehicle interface for the intersection system. Even trust in a system could affect the response time. Low trust may lead to drivers spending additional time verifying the problem, or ignoring the warning.

To be able to minimise false warnings a continuous risk level should be used (see chapter 2.2.1). This means that a situation has to be detected continuously for some time. A warning can then be given after the risk level has reached a prior specified threshold and the driver not already has begun to initiate a crash manoeuvre by steering away, releasing the accelerator, or braking.

When calculating the risk level buildings that mask drivers' view could be taken under consideration as well as the opportunity to integrate the Intelligent Driver Information System, IDIS, that are available in a Volvo car. This workload manager could adapt the in-vehicle intersection information according to the driver status and driver conditions. A reduction of the collision warning threshold could, for example, be done if the IDIS derives that the driver's workload is high or if he/she is engaged with a potentially distracting task or has lost the attention on the road. This could then generate to a triggered warning earlier than normal, giving the driver more time to respond.

7 Concept evaluation

In this chapter results from the evaluation of the concepts are presented. First the profile of sample is described. Then comments and opinions about placement, strain, interpretation of icons, information content and general impression about the different concepts are summarised. To be able to distinguish the concepts, the same names as given in chapter 6 are used, e.g. A1, A2, B1, B2. The chapter is finished off by the respondents' prioritisation of the system output.

7.1 Profile of sample

The evaluation was, as earlier mentioned, carried through with fourteen drivers in the range from 21 to 57 years old, although the majority of them were between 25 and 39. Of the fourteen respondents, eight were males and six were females. Ten of them had been driving with a navigation system but only two with a LED. None of them had been driving with a head-up display.

Even though the respondents were asked to motivate and explain their standpoints some of them could not describe their opinions in words. They simply felt that something was good or bad, but could not explain why. This means that it was not possible to get comments from all respondents.

7.2 Information about an upcoming intersection

A scale from one to seven was used by the respondents when answering the questions during the evaluation. The questions could be seen in appendix C. The way people used the scale did however vary a lot (grade 3 for one respondent could be equal to grade 5 for another). Therefore grades were not used to compare opinions about concepts between different drivers.

Figure 16 presents the results from the evaluation in regard to the questions asked. The figure shows the number of respondents that preferred (put a higher grade on) a concept before the other in regard to placement, strain, interpretation of icons, information content and general impression. The piles do consequently not say anything about how good a design solution is according to the evaluation respondents. It is just a comparison between the concepts. Comments from the drivers do however highlight the concepts strengths and weaknesses. They are described further down.

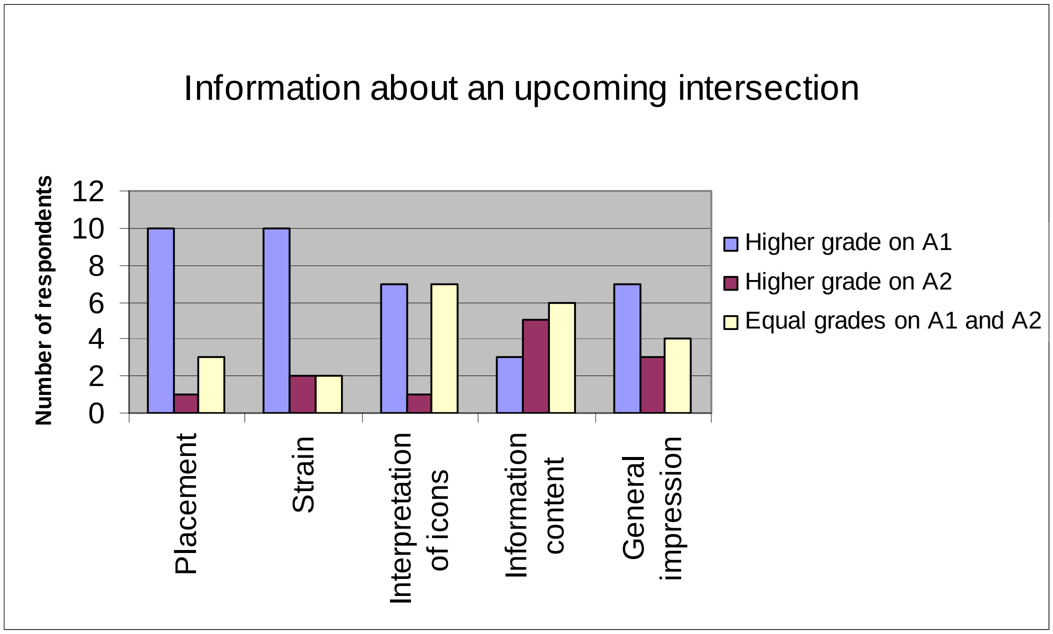


Figure 16: Results from the evaluation of the concepts including information about an upcoming intersection

Placement

Regarding the placement of the information about an upcoming intersection, ten respondents thought that the head-up display was the best location and only one thought that the centre stack display was the best. A frequent comment from those in favour of a HUD was that it is good that the information is in the driver's line of sight. They said that they are afraid of loosing the concentration of the driving task if the information is presented on the centre stack display. This since it is too hard to see information placed at that location.

Strain

When the drivers were asked about the distraction level of the concepts, concept A1 was considered to be a less distracting design. In general concept A2 was perceived as having too much information to look at and therefore experienced as too complicated.

Interpretation of icons

Half of the respondents considered that the icons in concept A1 and A2 were equally logical and easy to understand. Six of them thought that the interpretation of A1 was easier. Comments mentioned by two respondents were that it is too much information in the right nether corner of concept A2 and that the important part (the traffic lanes) is too small. A suggestion from one of the drivers was to enlarge the information about the traffic lanes and only have a small icon of how the intersection looks like.

Regarding the symbol of the type of an intersection one driver thought that it was very important that the symbols looked like the reality, e.g. a four-legged intersection could have very different appearance. The same comment was given for the concepts including information about other road users.

Information content

When judging whether the amount of information is too much, enough, or too little, six of the respondents perceived that the information content was equally satisfying in both concepts. Five drivers thought that the amount of information were more appropriate in concept A2.

A few drivers thought that the information in concept A1 is enough if it is a simple intersection. However, if the intersection is complicated it would be good to get information about lanes on the centre stack display. In general A1 was considered as providing too little information. It should preferably be more focus on the lanes. One respondent gave the suggestion that the HUD could give information only when the driver should change lane, and give no information if he/she is in the correct one.

Information that drivers appreciated the most in concept A2, was that they are able to see the traffic lanes. Many also appreciated the ability to get information about traffic regulations. The concept was seen as especially good for complicated intersections. Furthermore, two respondents said that the information is very usable for a driver from a foreign country. Regarding the amount of information, a few thought that it was good to get information about zebra crossings. On the other hand, some were of the opinion that such information is irrelevant. Two drivers were not interested in getting information about the traffic lanes at all, and one thought that the information was not enough. He would also like to know which traffic lane to take after the turn.

General impression

Even though concept A1 was perceived by some as having too little information, results from the question regarding general impressions talk in favour of concept A1. A few respondents thought however that a combination of the concepts would be best.

After filling the evaluation form out, the respondents were also asked if they would like to have such a system and whether or not they were willing to pay for it. The drivers were generally positive to get information about an upcoming intersection. Almost everyone would like to have such a system, especially when driving in unknown areas. One driver did however not see how the system could help him since he never apprehend that it is important to get such information. Out of the thirteen positive drivers, only one said that the system was not interesting if extra money had to be paid to get it.

7.3 Information to notify the driver about other road users

As for the information about an upcoming intersection the majority of the respondents preferred to get information about other road users on the head-up display. They thought that an intersection could be complicated and therefore it is good that they do not have to turn their gaze away. Regarding the distraction level, drivers were rather unanimous; concept B1 was perceived as being less distracting than concept B2. Drivers did however disagree about the interpretation of the icons, the information content and the general impression. Figure 17 shows a diagram of the answers from the evaluation and comments on the questions drivers disagreed about are then presented.

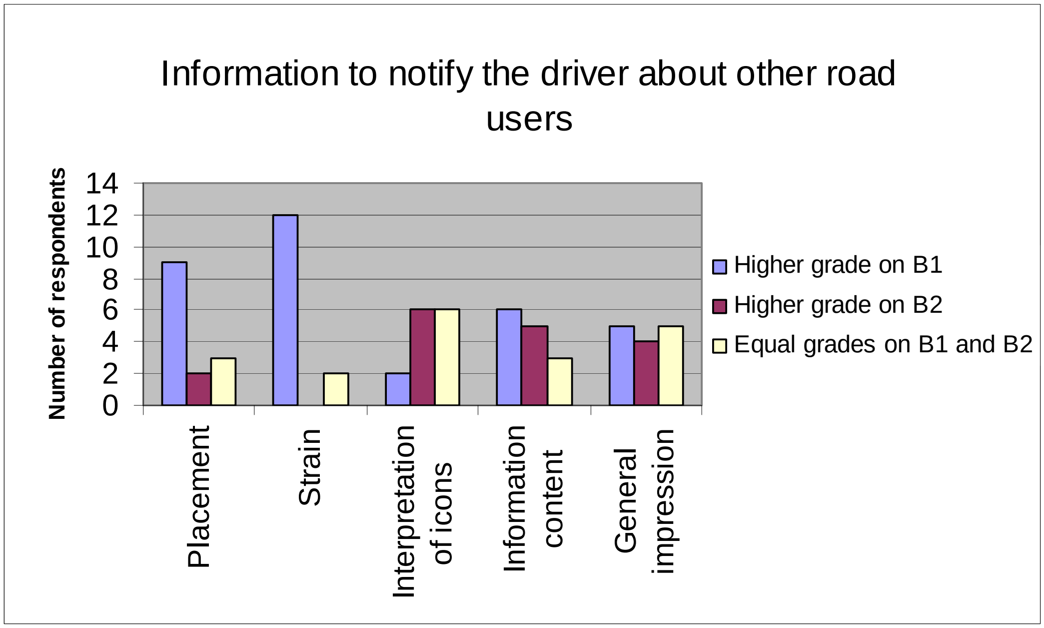


Figure 17: Results from the evaluation of the concepts including information to notify the driver about other road users

Interpretation of icons

When discussing how understandable the icons in the different concepts are, six drivers were of the opinion that the icons in concept B2 are more logical and easier to interpret. This since the driver does not know what to look for in concept B1. Six respondents thought however that there is no difference when it comes to the interpretation of the icons. One test respondent was worried about a risk of getting prepossessed in false security if the driver cannot trust the system completely. If no dots or symbols appear, the driver could think that it is safe to drive and therefore not self pay much attention to possible road users.

Information content

Opinions about the information content and the strengths and weaknesses in the different concepts were mixed.

Six respondents thought that the information amount in concept B1 is enough and that concept B2 is presenting too much information. All they want to know is the road users they have to considerate. It does not matter if it is a vehicle or a pedestrian. Furthermore it was pointed out that it was a good design in regard to the display. It is also good that the driver can use common sense to look for the road users. Some respondents said though that the design of concept B1 was too elementary and that they would like to know more. One respondent said that it is irrelevant to get information about vehicles, since they are always there. It would be better if the dots only represented vulnerable road users since they are the ones that are hard to detect.

Five respondents said that it is important to know the type of the road users to be able to know what to look for. They therefore preferred concept B2. A few did even want more information. Two respondents would like to know if the road users are moving or standing still, one would like to know the heading of the road users and one would like to know about the visibility in the intersection. The last mentioned respondent thought it would be good to know that something is obscuring the bicyclist to be able to be extra observant. For an image of the scenario see figure 4a. Another driver was worried that the prioritisation described in chapter 6.2.2 could become dangerous. The prioritisation means that if there is more than one object on a segment, only the object that has the highest priority will be shown. The respondent said that if an icon of a bicyclist were shown, the driver would only look for such a road user. When a bicyclist is seen in reality, the driver would think that the situation is under control. There could however be pedestrians there as well and the driver would not look for them. This could then lead to a dangerous situation. A suggestion to symbolise that there is more than one road user in an area was given by another respondent. The idea was to make the icon look like it is on top of a pile.

General impression

The general impressions about the concepts were mixed. Five respondents preferred B1, four preferred B2 and five put an equal grade on the two concepts. The respondents were also asked if they would like to have a combination of the two concepts. Five drivers thought that was a very good idea, since they complement each other very well. The information on the HUD shows where to be observant and if the driver is interested in getting more information he/she could look at the centre stack display. Many of the ones not interested in that kind of solution said that they would never look at the centre stack display anyway.

Getting information about other road users in an intersection, and thereby knowing where to be extra attentive, was apprehended as useful. The great majority would like to have such a system, but two of them would not pay extra for it. It was perceived as especially good when having a visual obstruction or reduced visibility. The two not interested in the system did not feel insecure in an intersection and thought that receiving information would only lead to a risk of loosing the concentration.

During the interviews conducted earlier in the thesis work, an option to receive information on explicit demand was discussed. The same discussion took place with the respondents of the evaluation study. Six of them thought it was a good idea to be able to easily turn the system on and off. Four were either of the opinion of never wanting the information or always wanting the information. The remaining four were unsure, thinking it might be too much to deal with.

7.4 Information that helps the driver with gap judgements

Regarding information that helps the driver with gap judgements, impressions of the concepts were mixed. Most respondents did however consider the design of concept C1 to be less distracting than concept C2. This since the latter concept includes several elements. See figure 18 and comments below it, for other results from the evaluation.

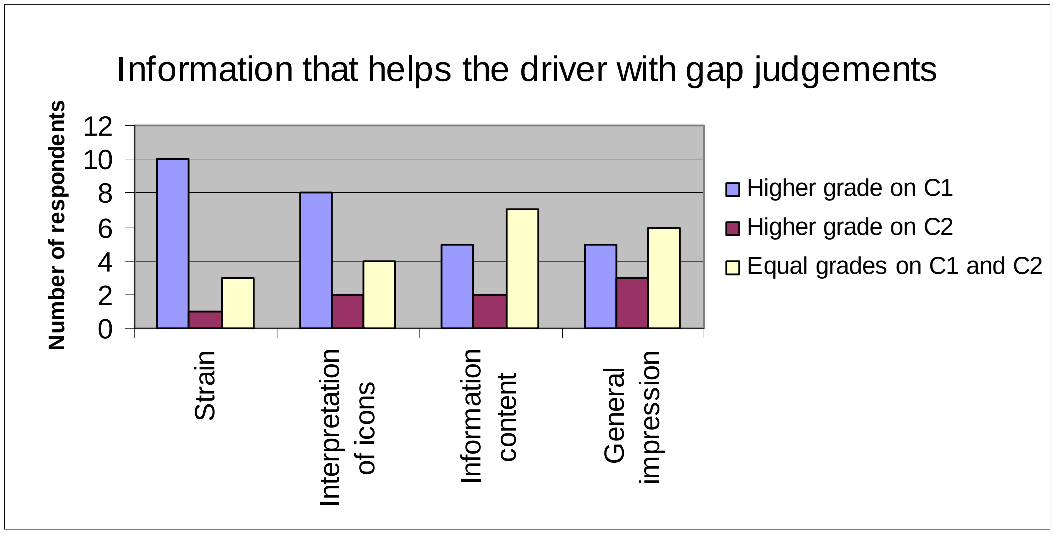


Figure 18: Results from the evaluation of the concepts including information that helps the driver with gap judgements

Interpretation of icons

Regarding the interpretation of the two concepts eight drivers thought that C1 was more understandable since it is distinct and simple. One respondent thought it was very good that a red arrow indicated an unsafe gap, but that all the other colours would make him distracted. Some details in concept C1 could however be questioned. Is it possible for colour-blind people to notice the different colours? Could it be hard to know when you have reached a maximum level, is there for example a redder arrow?

Only two respondents preferred concept C2 when putting grades regarding the interpretation of the icons. A comment in favour of that design was that it is good for colour-blind people. If they cannot see the colours they can still see the bar rising. A few also liked that it felt more continuous than C1. This since it is possible to see how the scale is changing. A few said on the other hand that it is hard to decide how much of the pile that is filled. Furthermore the interpretation was not perceived as logical to all. Some did not understand what it really means if two more fields are filled. Furthermore, one respondent would prefer to have the red field at the bottom. When the scale is full, it would mean it is a safe gap. The respondent was referring to playing computer games, when it is often good to get a full scale.

Information content

Half of the respondents thought that the information amount was satisfying in both concepts. By five respondents the scale in C2 was however considered as too complicated and five grades as too much information.

General impression

Again the general impressions of the concepts were mixed, with five respondents in favour of concept C1 and three in favour of concept C2. Six drivers put an equal grade on the two concepts.

Getting support with judging gaps was however not considered particularly helpful. Only five respondents would like to have such support and four of them were women. The male would not pay extra to get such system. The remaining drivers said that they would not trust the system and that they need to do the judgement by them self anyway. Some mentioned that they were afraid that the system would increase the collision risk. This since people might trust the system too much and thereby neglect to be observant. A driver could for example be waiting for the levels to change and then drive without looking carefully.

7.5 Collision avoidance system

The evaluation of the collision avoidance system ended up with the most unanimous results. Most drivers preferred the LED-solution. Opinions were however mixed regarding concept D2 and D3. To get more detailed information about the opinions from the evaluation see figure 19. The rest of this subchapter presents the drivers' comments.

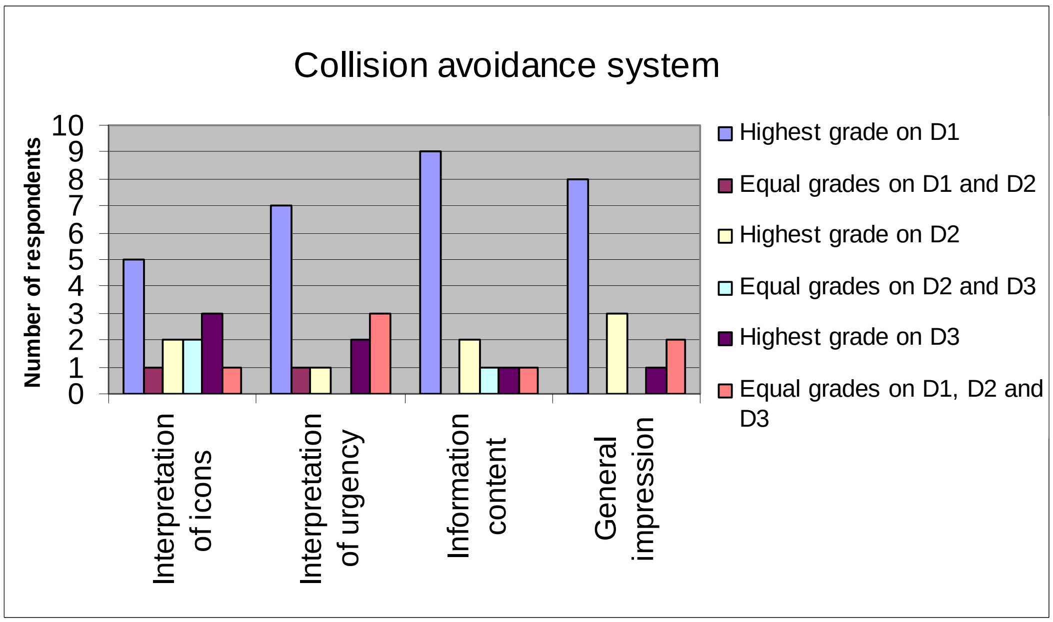


Figure 19: Results from the collision avoidance evaluation

Interpretation of icons
Regarding how logical and easy the different concepts are to understand, the opinions were mixed. Five respondents thought that concept D1 was the easiest to interpret, two preferred concept D2 and three preferred concept D3. The remaining four did not consider a single concept to be the best in regard to the interpretation of the icons.

Comments in favour of both concept D1 and D2 were that it is good that these concepts do not look like other information in the car. Furthermore, one respondent mentioned that the LED reminded of the braking light from a car in front, indicating that the driver has to brake. Two respondents thought however that too much interpretation is left to the driver and one was worried about the risk of misinterpreting the information. Maybe the driver thinks that he/she should manoeuvre the vehicle in the direction of the lights.

A few respondents pointed out that they liked that concept D2 was from a driver's perspective. One driver was however worried about getting confused and one said that in concept D2, it felt like the collision was already made. Another one did not like the colours. Red is associated with danger and in concept D2 that means that the car is more dangerous than the crash. This is however not the case. The respondent would therefore prefer that the car was yellow and the crash symbol red.
Regarding concept D3, some respondents were afraid of getting confused since they never think in terms of an intersection. On the other hand two drivers though that concept D3 was the easiest one to understand, especially in regard of knowing where the danger is. One respondent thought that it was good that the symbol looked like the information presented in the other concepts but that it needed to be combined with concept D1.

Interpretation of urgency
Respondents were also asked if the urgency of the warnings were understandable since a critical warning requires an immediate response. Half of the drivers considered concept D1, with the LED, to be the concept that best showed the criticality of the warning. It is experienced to be simple and distinct and lightening red indicates a crisis. One respondent were however worried that such a warning would make the driver too stressed. Another respondent thought that D2 was the best at showing the urgency level because it felt like it appears in the face. This respondent said that it felt like the LED light appeared lower down on the windshield. A disadvantage mentioned by a few respondents is that the symbols in D2 and especially D3 are too similar with other driving information (for example concept A1 and B1). They would thus not realise that it is a critical situation. Some respondents mentioned that they thought that the sound was the primary source for understanding that they are in a critical situation.

Information content
Whether the information content is satisfying or not, most drivers considered that concept D1 had the best amount of information. A frequent comment was that concept D2 and D3 had a too high level of information to be appropriate in a critical situation. Two respondents thought that it is enough to know that there is something about to happen, making the driver attentive. Another respondent thought that the LED was the best at indicating where the danger is.

One driver, which had been driving with the LED in the today's Volvo cars, thought that the LED of today is too rough and that it is much better if it is constructed like the one in concept D1 (larger and also shows the direction of the hazard). However, two respondents thought that it is enough to know that it is a danger somewhere and thus that it is not necessary to light the LED in the direction of the hazard.

General impression
The warning system turned out to be appreciated by everyone. All of the respondents would like to have such a system, but one respondent would not pay extra for it. Eight drivers preferred to get a warning like the one in concept D1. Three put the highest grade on the general impression on concept D2 and one on concept D3. Two respondents thought that the design of all concepts were equally good.

Although some respondents liked the idea of an automated system, two of them thought it was frightening and said that reducing speed is not always the best solution to an impending crash. Sometimes steering could be better. Regarding the sound component in the warnings, one respondent were worried that the system could increase the severity of a crash. If the sound comes from the direction of the hazard, the driver will turn the gaze at that direction and thereby there might be a risk that the driver also turns the steering wheel towards the hazard.

The respondents were also asked if they would like to receive a warning if they were about to break regulations, for example red light and stop sign violation. This was though not included in the driving scenario. Twelve of the fourteen drivers were positive to regulation warnings and two said maybe. Many of them did however want to be able to self decide for what regulations the system should warn.

7.6 Prioritisation of system output

In order to know what to set focus on when developing the intersection system, the respondents of the evaluation were asked to prioritise the system outputs from 1 to 4. One indicating the most important output (the one they would like to have the most) and four the least important.

Putting all respondents' opinions together and calculating the mean for the different systems gave the result that the collision avoidance system was considered as most important. It was followed by the information about an upcoming intersection and the information about other road users. These two system outputs ended up with equal mean values. Information that helps the driver with gap judgements was considered to be the least important.

8 Discussion

This final chapter reflects over the method used in this thesis and discusses the results from the interviews and the evaluation. It further presents advantages and potential problems with the design. This chapter also gives suggestions of how to continue the work with designing an intersection system and of possible future fields of application.

8.1 The use of the human centred design process

The use of the human centred design processes for interactive systems, ISO 13407, has been very good for the development of the first design concepts for an intersection support and warning system. If more time had been available, some stages could however been made in a more depletive way. To be able to distinctly evaluate whether an upcoming intersection system really meets the usability requirements, some of them could have been made measurable. This could for example be done by using questionnaires with grades. To be able to draw conclusions on such a measurement, the results need however to be statistically secured, i.e. include a large amount of respondents. The requirement “Drivers must be satisfied with using the system” could then be measurable by saying “On a scale from1 to 7, with high scores indicating high extent of satisfaction, overall satisfaction ratings must be 5 or higher for 95 % of the users”.

Prototypes in form of paper visualisations cannot capture a system’s performance. The optimum would have been to be able to evaluate the different design alternatives with drivers in a simulator and under real-world conditions. Due to time restrictions, this was however not possible. Evaluation in a simulator would have given more information about drivers’ acceptance and behaviour with the designed concepts. A discussion of interesting factors to investigate in such a study is given in chapter 8.2.2 and 8.2.3. The results from the evaluation within this thesis are however a first indication of drivers desires and attitudes towards an intersection system. Respondents had though, prior to this study, no exposure to a support and warnings system like the one investigated. The responses reflect thus an immediate impression, as opposed to the preferences drivers might state after several weeks of use.

Since the aim of this thesis was to conduct a first concept of a driver-vehicle interface only one evaluation with end-users has been made and redesign and more evaluation have to be done. During later development stages, it can be notified that requirements need to be reformed and more specified. In that case, the design activity “requirements” should be considered again (see dotted arrow in figure 1).

8.2 Discussion of the results from the evaluation

Findings from the evaluation may reflect the respondents’ previous experience with getting information and alerts. Many people tend to like things they are used to. On the other hand, people have experience with both advantages and disadvantages in an existing solution. If their total judgement is negative, they would probably prefer a new solution. With this in mind, evaluation respondents were asked if they had been driving a car with a navigation system or a head-up display. The result shows that no one had driven a car with a head-up display, but that ten respondents had used a navigation system. No one said however anything negative about the navigation system during the evaluation. Drivers may therefore be more accustomed to get information similar to the navigation system and thus automatically prefer suggestions where the information is located on the same display as the navigating information. This was however not the case. Most respondents said they would prefer to get the information on the head-up display, since they saw the big advantage to have information in the line of sight. Many of them said though that they had to drive a car with such a solution to be sure that it is not too distracting.

Despite from the preferred location of the information and to some extent the question regarding strain, results from the evaluation show that opinions about an intersection system are diverse. The mixed opinions might be due to the fact that drivers' characteristics are very different. This could thereby indicate a solution where the individual driver could make options regarding, for example, the information amount. There is a possibility that the perceived need of information might be dependent on the driving experience. Therefore, young and old drivers may appreciate different concepts. This was however not the case. It is though important to keep in mind that the evaluation was not made in a real driving environment. There are huge differences between the evaluation environment (a room), with no competing stimuli or control requirements, and real-world conditions. Many respondents said it was hard to imagine what they would prefer if they were actually driving a car with the intersection system. Perhaps tests in a simulator could give more evident results. Most likely is however that the mixed opinions are a result from the low number of respondents. User tests based on more drivers would lead up to a better base to draw valid conclusions from.

Regarding what to include in the system output, warnings are perceived as being most important and information that helps the driver with gap judgements as least important. In fact, only five of the fourteen drivers in the evaluation study and three of the eight drivers from the interviews would like to have such a system. Even though the INTERSAFE study (see chapter 5.2.3) tested a turning assistance with favourable results, it could not be recommended to put effort in such a system. At this point it is better to focus on the system outputs that are perceived as satisfying to drivers. They are the ones that are going to buy and drive the future cars. The gap judging system is therefore not discussed in detail. Interesting is however that four of the five positive drivers to such a system were women. The ones not interested in the system said that they would not trust it. This result is in accordance with a study made by Jonsson and Chen (2007). They found that female drivers trust and like in-vehicle information system more than male drivers. A distinct difference in opinions between female and male drivers could however not be seen for any other system output.

A discussion about the other system outputs could be read in the following three subchapters.

8.2.1 Information about an upcoming intersection

Results from the crash data analysis, the interviews and the evaluation indicate that drivers would accept and benefit from a system giving information about an upcoming intersection. This because it gives the driver opportunity to plan the driving and more time to change lanes. It is especially important when driving in an unknown area, in a complicated intersection or in a foreign country. The evaluation does however show that a redesign of the suggested concepts needs to be done. The head-up display was by far the most appreciated location of the information. The information content in concept A1 was however perceived as too little. The respondents would like to have more focus on the lanes. A concept for a HUD-solution including information about the traffic lanes should therefore be done. Furthermore, the concept placed on the centre stack display should also be redesign, with a view to be less complicated and more readable.

8.2.2 Information to notify the driver about other road users

Results from the crash data analysis and the evaluation also indicate that drivers would accept and benefit from a system giving information to notify the driver about other road users. Regarding the location of such information, the HUD was perceived to be better than the centre stack display. Opinions were however mixed about the interpretation of icons, the information content and the general impression of the two suggested concepts. Some of the evaluation respondents thought that it is enough to know that there are road users to considerate. This is in accordance with the interview study, where the majority said that they did not want to know the type of the vulnerable road user. Some evaluation respondents thought on the other hand that it is important to know what kind of road users to look for. No suggestions on redesign of concept B1 were given and the redesign suggestions for B2 included inserting more information. This could for example be the heading of the road user, information about visibility and whether the road users are moving or standing still. In addition, further graphical work could be done with concept B2, for example showing the appearance of the intersection like a realistic sketch or like a photographical image. The mixed opinions about the concepts indicates that the best solution could be to let the driver decide how he/she would like to receive the information; like concept B1, B2 or as a combination of them. Another good idea could be to let the driver decide which road users to show, since a few mentioned that they were not interested in vehicles. This because vehicles are more easily seen by the driver than vulnerable road users are.

One conclusion from the guidelines in chapter 2.2.1 and mentioned by many drivers during the evaluation, is the need for precision. The system output must have a high degree of accuracy and reliability to be able to command credibility. Most of all, the system must not lead to significant negative changes in behaviour, for example reduced attention to traffic situations or increased driving task distraction. Furthermore, the system must not lead to a cognitive tunnel vision, meaning that people concentrate on the variables they find most important (for example pedestrians) at the exclusion of others. This could especially be the case in concept B2, since it provides more detailed information about the type of road user.

There are also some other disadvantages with concept B2 that has to be taken under consideration. First of all, the driver must not look into the vehicle for too long when approaching an intersection and the information must therefore be easily interpreted. Whether or not the concept B2 is too detailed must therefore be tested in a driving simulator or under real-world conditions. Furthermore, the false alarm rate will probably be higher if the system must give information about the type of road user. If the driver is looking for a pedestrian but there is only a bicyclist in that area, he/she will see that as a false alarm. This will though not be a problem in concept B1, which only shows that there is a road user present. The question is however if B1 will be seen as too messy with dots everywhere, in cases when there are road users in all areas in an intersection. The concept has therefore to be tested with different numbers of road users.

The reason for discussing an option to receive information only on explicit demand was the results from the WATCH-OVER questionnaire study. It showed that the majority would not like to receive information about vulnerable road users. The interview study within this thesis indicated the same attitude; most drivers would not like to have information about other road users. When discussing the explicit demand option all of the interviewees were however positive to getting such information. They thought that there are situations where the information could be very helpful. It is however important to keep in mind that these results are not based on a concrete design solution. The respondents were only supposed to think about what information they would like to receive, without taking into consideration how the information were going to be presented. The result from the evaluation study revealed however that the great majority would always like to have information about road users. Since these respondents got the opportunity to make opinions about concrete design concepts, these results are more reliable. It is though important to keep in mind that these drivers were told about a driving situation where the interviewees thought that a support system could be helpful. The positive outcome from the evaluation talks in favour of not getting information on explicit demand. Furthermore, such solution could lead to drivers becoming overloaded by demands and thereby loosing their attention.

8.2.3 Collision avoidance

The warning system is perceived as being the most important output. This is based on the prioritisation made by the drivers in the evaluation study. Even the great majority from the interviews and the WATCH-OVER study would like to receive warnings.

The use of a LED in concept D1 was evaluated as the best design solution. Driver response and behaviour when using this system need however to be investigated in a simulator. It is important to make sure that the system elicits the desired driver response, with high level of accuracy. There might for example be a risk to misinterpret the information and manoeuvre the vehicle in the direction of the lights and the sound. To be able to have something to compare acceptance, behaviour and response time with, concept D2 could be evaluated in a simulator as well. The intersection symbol in concept D3 is namely too similar to other system output information and should therefore be neglected. Given that guidelines recommend a flashing symbol to draw attention (see chapter 2.2.6.1) this could be tested when evaluating concept D2 in a simulator.

Since hearing is the primary modality of the warning, it could be interesting to see whether or not the use of different symbols has a large impact for hearing people. Furthermore, the visual display serves as a backup and a supplement if the auditory signal is masked by in-vehicle noise or for drivers with hearing impairments. Tests need therefore to be done under such circumstances and with such drivers. The use of a tone could be replaced in the future with an appropriate auditory icon, if further research shows sufficient data on auditory icons as imminent crash warnings.

A driver must however not trust the warning system too much. This since too high trust in a system may lead to drivers neglecting other typical safety behaviour, such as maintaining their own vigilance level (see chapter 2.2.1). As could be read in the Volvo owner's manual S80 (2007), the driver should:

> "Never wait for a collision warning. The system is designed to be a supplementary driving aid. It is not, however, intended to replace the driver's attention and judgement. The driver is responsible for maintaining safe distance and speed, even when the collision warning system is in use." (Volvo Cars, 2007e)

8.3 Number of intelligent intersections could impact the design

It is important to decide if the intersection support and warning system should be applicable in every intersection or only in some. For example complicated intersections and intersections were lots of accidents occur. If the system is applicable in many intersections it could perhaps influence drivers' acceptance with false alarms and annoyance of information.

Even more important is to discuss and investigate how to do handle situations where the system is unable to inform or warn the driver. This could either be due to the system not functioning, or if no information is available in an intersection. As mentioned by one driver in the evaluation study (see chapter 7.3), the habituated driver could interpret the absence of information about other road users as an implied indication of a safe situation. This is especially the case if most intersections are to be equipped with sensors. Otherwise, there should be less concern about drivers expecting to get information at all intersections and responding inappropriately at unequipped ones. The best would however always be to inform the driver if information about an intersection is available or not. Concept B1, where information about other road users is shown as dots in an intersection symbol, could for example present an empty intersection symbol to indicate that there is an intersection system available. If no dots are shown, no road users are present. If an intersection does not have any information, no intersection symbol will be given at all. In this way, the driver can easily distinguish if there is no information available, or if information is available, but no road users are present. This interpretation may however not be intuitive, but must be learned.

8.4 Designing for management-by-awareness

The concepts derived and evaluated within this thesis can be seen as belonging to the theory of different operation strategies; management-by-awareness and management-by exception. The operation in this case is a driver manoeuvring the vehicle in an intersection.

Management-by-exception refers to an operator who waits for an exception, e.g. a warning, to occur and then deals with it. Whereas management-by-awareness means that the operator will actively monitor key variables to be able to gain situation awareness. (Andersson, Jansson, Sandblad, 2007) Situation awareness gives the operator an opportunity to maintain a high degree of readiness for possible changes in the environment, to be proactive in making decisions and thereby reducing the risk of errors. (Endsley, Bolté, Jones, 2003)

Situation awareness includes:

- Perceiving status of relevant elements in the environment (e.g. see other road users, signs, traffic lights)
- Understanding what these elements mean in relation to relevant goals (e.g. yellow light indicates proceeding with caution, based on the distance from the intersection)
- Predicting the future actions of the elements (e.g. a driver knows that if he/she proceeds into the intersection he/she is likely to be struck by cars on the crossing street)

(Endsley et al., 2003)

Having different approaches to operation strategies, results in radically different design solutions of the support system and its interface. The support system must however correspond to the preferred operator strategy to be the most efficient. (Andersson et al., 2007)

As derived in the task analysis (see chapter 4.2) drivers perform their task by being updated about the local surrounding. To be able to do this, situation awareness of the vehicle's state is however also needed. Today this is given by different support systems that for example tell the driver when to refuel. No information system that supports the driver gaining situation awareness about local surrounding world information (through providing enhanced and augmented information) has however been developed. At least not during daytime, in some cars night vision is available. The concepts including information about an upcoming intersection and information to notify the driver about other road users, can therefore be seen as a step towards designing in-vehicle systems for "driving-by-awareness".

Even though drivers want to manoeuvre their vehicle by being updated, they sometimes get into situations where something unexpected happens. Often they have to deal with it under time pressure. It could for example be a child running over the street. Drivers never wait for such situation to appear, but tries to predict other road users' actions. This is however not always possible, and they therefore sometimes have to operate by the management-by-exception principle. The suggested intersection collision avoidance system gives the driver information about an unexpected situation before it leads to an accident. It could therefore be seen as being designed for "driving-by-exception".

8.5 In what traffic densities will the system be most helpful?

In chapter 4.2.1 it was described that drivers overloaded with demands could lead to accident and near-to-accident conflicts. One could therefore hope that the intersection system would be most useful in complex traffic situations. A study by Jonsson and Chen (2007) does however show the opposite. They investigated 17 driver's responses and attitudes towards an in-vehicle system in high and low density traffic. The system did for example notify the driver by a speech message saying, "There is a busy intersection ahead". Both driving performance and questionnaire data gave the result that the in-vehicle system was perceived to be more helpful in low traffic situations than in high traffic. (Jonsson & Chen, 2007)

Even though the suggestion for the intersection system does not include speech messages, one can assume that results might be the same for this system. Drivers may see more potential of having the system turned on in low traffic situations to alert them of where to be attentive. In high traffic situations, when the driver has to be more active, the same information may be perceived as too distracting.

8.6 Recommendations for future research

The aim of this thesis was to develop and evaluate the first concepts of a driver-vehicle interface for an intersection support and warning system. As mentioned earlier in chapter 8, results have shown that some concepts should be developed further to achieve maximum benefits. Furthermore, warning concepts regarding breaking regulations should also be taken under consideration. The iterative design process must thus be made in further steps. With help from tests in simulators and under real world conditions, a more precise and representative set of findings could be gained. It is important to investigate how drivers will react to the intersection system information in different situations, both in form of objective and subjective results. Objective results could for example include driver response, reaction time and reduced attention to traffic situations or increased driving task distraction. Subjective results refer to drivers' impressions and acceptance.

8.6.1 Future fields of application

Another recommendation is to investigate if developing for situation awareness could be beneficial in more driving situations. For example if it could be useful for drivers to get information about other road users in sharp curves or at unsupervised zebra crossings, where drivers have a duty to give way for pedestrians.

In addition, the ability to include a safety driving school could be discussed further. When a trip is completed it could be possible get a driving review showing unsafe situations, why they became unsafe and tips on how to improve the driving style to a safer level. Providing drivers with information that identifies risky driving manoeuvres could help them to learn from their mistakes and thereby reduce crash propensity. Since the intelligent intersection system will calculate the risk level for a collision, it could be possible to log information from all situations that exceed a certain value. The logging information could for example include a map from the navigation system or up-to-date information about the appearance of the intersection from the intelligent intersection itself. Furthermore, status of the turning indicator, information from the IDIS system and position and heading of the interesting road users from the intersection system could be logged.

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Appendices

Appendix A: Interview questions (in Swedish)

Svara på frågorna utifrån din egen uppfattning om vilken slags information som skulle kunna underlätta för dig att på ett säkert sätt köra igenom en korsning. Försök att inte tänka på hur informationen skulle presenteras i bilen, utan bara på vilken information du skulle vilja ha.

1. Ålder
☐ < 25 ☐ 25-39 ☐ 40-54 ☐ 55-65 ☐ >65

Kön ☐ Kvinna ☐ Man

Ingen olycksrisk

2. Skulle du vilja informeras om en kommande korsning (vilken typ och hur långt det är till den)?

3. Skulle du vilja informeras om närvaron av trafikskyltar (varningsmärken, väjningspliktsmärken och förbudsmärken), så att du i förväg vet vad som kommer att möta dig i en korsning?

4. Skulle du vilja få en rekommenderad hastighet när du närmar dig en korsning?

5. Skulle du vilja informeras om närvaron av oskyddade trafikanter (fotgängare och cyklister), om det inte finns risk för en olycka?

6. Vilken slags information om oskyddade trafikanter skulle du vilja ha?

7. Skulle du vilja informeras om närvaron av andra motorfordon, om det inte finns risk för en olycka?

8. Vilken slags information om motorfordon skulle du vilja ha?

9. Vilket av följande alternativ föredrar du, om det inte finns risk för en olycka?
☐ Jag skulle aldrig vilja ha någon information
☐ Jag skulle alltid vilja ha information
☐ När jag känner att jag behöver information skulle jag vilja få den efter jag explicit angivit det (tex. genom att trycka på en knapp på ratten).

10. Om informationen endast skulle visas efter explicit begäran, vilken information tycker du då vore mest intressant att få?
Oskyddade trafikanter, andra fordon, trafikskyltar

Följande frågor handlar om information som kan underlätta beslut i en korsning.

11. Skulle du vilja ha kontinuerlig information om trafikljus (om de visar rött, gult eller grönt)?

12. Skulle du vilja ha information som kan hjälpa dig att bedöma luckor i trafiken, där du hinner köra rakt fram eller svänga i en korsning?

13. Vilken slags information om luckor skulle du vilja ha?
Att det finns luckor i trafiken, storleken på luckorna (ankomsttiden för en närmande bil), olika säkerhetsnivåer på luckorna

14. Vilket av följande alternativ föredrar du?

☐ Jag skulle alltid vilja ha ovanstående information
☐ När jag känner att jag behöver information skulle jag vilja få den efter jag explicit angivit det (tex. genom att trycka på en knapp på ratten).

15. Skulle du vilja få en varning om du håller på att bryta mot trafikskyltar eller signaler?

Olycksrisk

16. Om det föreligger en potentiell olycksrisk med andra fordon eller oskyddade trafikanter, skulle du vilja få en varning om detta?

17. Vilka slags varningar skulle du vilja få för oskyddade trafikanter och fordon?
Bara en kritisk varning för en förestående olycka. Detta kräver ett direkt och korrekt agerande (bromsa eller styra undan från faran). Denna varning inträffar sällan, bara om risken för olycka är väldigt stor.

Olika varningar med olika grad av angelägenhet. En som informerar om en potentiell olycka. Den kräver uppmärksamhet och eventuellt ett agerande. Om olycksrisken ökar, en kritisk varning som kräver direkt agerande.

Appendix B: Scenario (in Swedish)

Information och support
Du är ute och kör bil i ett för dig okänt område. Du använder dig av ett navigationssystem (GPS) för att hitta rätt. Du närmar dig en korsning där du ska svänga vänster. Det finns möjlighet för dig att få information om vilken slags korsning det är du kommer att komma till. Nu är frågan vad du tycker om detta. (Utvärdering av koncept A1 och A2)

Korsningen saknar trafikljus och du har väjningsplikt. Till höger och vänster om dig finns stora byggnader, så du har begränsad möjlighet att se trafiken. 200 meter innan du kommer fram till korsningen finns möjlighet att få information om trafikanter i korsningen. I korsningen finns två bilar, två fotgängare och en cyklist. Vilken information du skulle vilja ha och på vilket sätt? (Utvärdering av koncept B1 och B2)

Nu har du stannat vid korsningen och planerar att göra en vänstersväng, men biltrafiken är intensiv och du måste vänta tills en lucka uppstår för att kunna genomföra din sväng. Du måste ta hänsyn till bilar från både vänster och höger. (Utvärdering av koncept C1 och C2)

Varningar
Du kör vidare och kommer till en annan korsning. I den här korsningen kör du rakt fram men missar att uppmärksamma en fotgängare som korsar din väg efter korsningen. Det resulterar tyvärr i en olycka. Skulle någon information kunnat hjälpa dig att förhindra olyckan eller åtminstone gjort den mindre allvarlig? Exemplet anger varningar för fotgängare, men kan också vara varningar för cyklister eller andra fordon. (Utvärdering av koncept D1, D2 och D3)

Appendix C: Evaluation form (in Swedish)

Ålder: Man / Kvinna

Ringa in den utrustning som funnits i en bil du kört: Navigationssystem / Head up display / LED

1	2	3	4	5	6	7

Håller inte alls med → Håller helt med

	Idéer								
	A1	A2	B1	B2	C1	C2	D1	D2	D3
1. Placering									
1.1 Detta är den bästa placeringen för informationen									
2. Belastning									
2.1 Designens distraktionsnivå är låg									
3. Tolkning av information									
3.1 Symbolerna är lätta och logiska att förstå									
3.2 Man förstår graden av allvarlighet/hur brådskande det är									
4. Informationsinnehåll									
4.1 Det känns som att mängden information är lagom									
5. Magkänsla									
5.1 Enligt min uppfattning är helhetsbetyget för denna design mycket bra									

Rangordna systemen A, B, C och D utifrån vilken du tycker är viktigast, med 1 som det system du helst vill ha och 4 som det du minst vill ha.

A. Information om en korsning ☐
B. Information om andra trafikanter ☐
C. Support för att bedöma luckor ☐
D. Varningar ☐