THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Designing Future Advisory Traffic Information Systems

A Step towards Cross-Regional Adaptive Design for Improving Driving Safety and Comfort

Min Juan Wang

CHALMERS

Department of Applied IT
Division of Interaction Design
Chalmers University of Technology
Gothenburg, Sweden 2015

Designing Future Advisory Traffic Information Systems
A Step towards Cross-Regional Adaptive Design for Improving Driving Safety and Comfort

Min Juan Wang

© Min Juan Wang, 2015.

Technical report no 1651-4769:15

Department of Applied IT

Division of Interaction Design of Technology

Chalmers University of Technology

SE-412 96 Göteborg

Sweden

Telephone + 46 (0)-772 1000

Printed by

Chalmers Reproservice

Göteborg, Sweden 2015

Abstract

Advanced Driver Assistance Systems (ADAS) and autonomous driving capabilities have become increasingly widespread, and implementations already exist in cars today. Given these dramatic technological changes, human-machine interaction design is facing new challenges. One of the major challenges is the communication with the driver, as there is often a disparity between how the system behaves and the driver's expectations. Another difficulty is that drivers may over-rely on the automation systems, and this reduces situation awareness, which in turn creates problems in reclaiming control when necessary. Furthermore, ADAS developments are traditionally based on drivers' requirements from mature markets, such as Europe, the US and Japan. But how would ADAS perform in China, where there is dense and mixed traffic?

The aim of this thesis is to gain better insights into cross-regional adaptive design on advisory traffic information systems. The purpose of advisory systems is to provide foresight traffic information to support the driver's situation awareness. To fulfill the aim, the studies have departed from a user-centered design approach in order to understand what drivers really want. In addition, different traffic scenarios were integrated into the design procedure to identify the contextual design constraints. Two design requirements studies and two driving simulator studies have been carried out with both Swedish and Chinese drivers.

The information requirement studies in this thesis showed that the similarities between Swedish and Chinese participants are greater than the differences. For example, they have similar design preferences and information requirements when interacting with a single road user. However, interesting differences were found when multiple road users were involved in the situation, e.g., when *entering ramps*, *cutting in* or *changing lanes*. The driving performance results indicated that advisory traffic information systems assisted Swedish and Chinese participants in different ways due to the different regional driving strategies and habits. Moreover, acceptance results also emphasized that an interface design entirely carried out in one region will likely result in lower user acceptance in another region. To conclude, cross-regional adaptive designs should focus on specific situations where the regional difference occurs, making it a feasible approach to a successful global design.

Acknowledgements

First of all, I would like to thank my supervisor Professor Fang Chen for her sincere support and constant guidance. Professor Chen has taught me a new perspective of thinking in both research work and everyday life. I would like to thank her for always taking the time to discuss my work whenever needed.

My co-supervisors, Dr Sus Lundgren and Professor Palle Dahlstedt deserve considerable credit for their constructive criticism throughout my work and always believing in me. Thanks to my industrial supervisor Samuel Palm for bringing the industrial perspectives into my research work.

Thanks for all the members in EFESOS and ADAS presentation projects, the inspiring and academic atmosphere in our project groups who inspired me. Special thanks to the present and former project managers Claes Edgren and P-A Jörgner who supported me throughout the projects and introduced me to all the industrial contacts that I needed.

Thanks to everyone in our Interaction Design division. The openness, friendliness and happiness from this group always made me feel like home. Here I would like to express my deepest gratitude to my masters students, Dong Sun, Bo Chang and David Marshall for the great contributions they have made in my research work.

Now, my friends! At a breakfast on a lovely Sunday morning when you had to discuss my boring statistics results, or even when I asked you to do my housework because I had a paper deadline. After all the crazy requests from me, I am grateful we are still best friends.

In the end, thank you Jin! Without your love, patience and support, I would not have been able to make it. To my lovely boys, as you always believe your mum is a rocket scientist and unbeatable which makes me want to do my best in my work. My parents, for your love and support throughout the years and for allowing me to explore my ideas without too many boundaries. I know this has been tough for you as Chinese parents.

List of appended publications

This thesis is based on the following papers, which will be referred in the text. The papers are appended at the end of the thesis.

Paper 1

Wang, M. J.*, Li, Y. C., & Chen, F. (2012). How can we design 3D auditory interfaces which enhance traffic safety for Chinese drivers? In Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, ACM (pp. 77–83)

Paper 2

Wang, M. J.*, & Chen, F (submitted): How to do adaptive designs on 3D Auditory Advisory Traffic Information System? - A comparison design requirement study between Sweden and China

Paper 3

Marshall, D. *, & Wang, M. J. (2012) Development of an In-Vehicle User Interface for Traffic Information Presentation. In Proceedings of the 44th Annual International Nordic Ergonomics and Human Factors Society Conference, Saltsjöbaden, Sweden

Paper 4

Wang, M. J.*, Duan, L., Wang, J. X., Li, L., Sun, D., & Chen, F. (2016). Drive Advisory System : Do Swedish and Chinese Drivers Appreciate It in the Same Way ? International Journal of Engineering and Technology, 8(4), 286–292.

Distribution of work

Paper 1

The first author planed the study, carried out the focus group sessions, analyzed the data and wrote the paper with continuous support from the two co-authors.

Paper 2

The first author carried out the focus group planning and focus group sessions together with a master student Dong Sun. The first author analyzed the data and wrote the paper. The second author provided continuous feedback through the study and writing process.

Paper 3

The first author planned and conducted the simulator study with continuous support from second author. The first and second author wrote the paper together.

Paper 4

The first author duplicated the simulator study from Paper 3 in China with support from other authors. The first author analyzed the data with the supports from third author. The first author wrote the paper with continuous input from other authors.

Additional publications

The following papers have previously been published within the research scope.

Chen, F., Giubega, C., Chen, P., & Wang, M. J. (2014). Designing an In-Vehicle Advisory System to Support Traffic Awareness, in *the proceedings of 10th ITS European Congress, Helsinki, Finland.*

Chen, F., Wang, M. J, & Duan, L. (2014). Advances in Intelligent Vehicles. *Advances in Intelligent Vehicles (pp. 291–318). Elsevier. doi:10.1016/B978-0-12-397199-9.00010-0.*

Wang, M. J., Sun, D., & Chen, F. (2012). Using naturalistic driving films as a design tool for investigating driver requirements in HMI design for ADAS. *Work: A Journal of Prevention, Assessment and Rehabilitation. 41, 4205–4212.*

Chen, F., Wang, M. J., Chan, X., & Li, J. (2012). How Shall We Design the Future Vehicle for the Chinese Market? *Work: A Journal of Prevention, Assessment and Rehabilitation, 41, 4265–4272.*

Table of definitions

3DAATIS	3D Auditory Advisory Traffic Information System
ATIS	Advisory Traffic Information System
VATIS	Visual Advisory Traffic Information System

Table of abbreviations

ADAS	Advance Driver Assistance Systems
EBA	Event Based Analysis
EuroFOT	European Field Operational Test
FCW	Forward Collision Warning
FOT	Field Operational Test
HMI	Human Machine Interaction
LDW	Lane Departure Warning
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situational Awareness Rating Technique
SemiFOT	Sweden Michigan Naturalistic Field Operational Test
TTC	Time to Collision

1 Table of Contents

1. Introduction

Advanced Driver Assistance Systems' (ADAS) functionalities and autonomous driving capabilities have become increasingly widespread, and implementations already exist in cars today. Examples include anti-lock brake system (ABS), adaptive cruise control (ACC), parking assistant, forward collision warning (FCW) and lane departure warning (LDW). Using these sensors, control algorithms and Vehicle to Vehicle (V2V) communication technologies, a car will enable to detect, monitor and react automatically to every object around it. Given these dramatic technological changes, human machine interaction (HMI) designs are facing new challenges. One of the major challenges is the communication with the driver, as there is often disparity between how the system behaves and the driver's expectation. When the system does not behave as expected, the driver tends to either abuse or reject the system entirely[1]. Another difficulty is that drivers may over-rely on the automation systems, and this reduces situation awareness (SA), which in turn creates problems in reclaiming control when necessary[2]. Furthermore, ADAS developments are technology-driven and also based on drivers' requirements from mature markets, such as Europe, the US and Japan. But how would ADAS perform in China, where there is dense and mixed traffic? An in-vehicle system that works very well and is of great value to drivers in one country may be of less value to those in another[3].

The objective of this thesis is to gain better insights into cross-regional adaptive design on advisory traffic information systems. The purpose of advisory systems is to provide foresight traffic information to support the driver's situation awareness. To fulfill the aim, the studies have departed from a user-centered design approach in order to understand what drivers really want. In addition, different traffic scenarios were integrated into the design procedure to identify the contextual design constraints.

1.1 Current limitations of warning design

The current designs of ADAS are still mainly technically driven and warning designs are widely employed [5]. New functions are added into a vehicle when the technologies are feasible rather than according to the drivers' needs. Normally, a warning is presented in a near crash situation; it alerts a driver regarding the urgency but does not indicate how to react, which means the driver often has no time to understand and respond to a warning information due to frustration and panic. There are two issues with current warning designs: Firstly, 'warning dilemma': A warning only makes sense when it takes place early enough. Furthermore a warning should only be a rare event or it would have a "cry wolf" effect, irritate and fail to generate the designated reaction. In order to reduce the influence of the warning dilemma, most collision warning systems only alert drivers in time-critical situations when collisions are imminent to reduce the false alarm rate but at the expensive of a higher miss alarm rate. Secondly, a critical warning on its own is not the best way to avoid collisions. These warnings are often binary rather than graded and provide little information regarding the type of threat or how it is evolving over time. If a driver misinterprets the warning and takes a wrong action or simply does not react in time, there is a risk that an accident will occur. In general, a warning signal was considered as a negative feedback by the driver and should be used minimally [6].

1.2 The benefits of an advisory traffic information system

According to Summala [7], a driver's goal is to drive without discomfort and stay within his/ her comfort zone. When the comfort zone boundary is exceeded and thus the safety margin violated, a driver will experience discomfort and try to adapt his/ her behavior in terms of corrective actions. To maintain the comfort zone, drivers need information from the surrounding traffic environment that makes it possible for them to anticipate potential hazards.

Previous studies have suggested that warnings should be activated when immediate actions are required to avoid a collision. ADAS design should also focus more on providing pre-warnings or advisory information to the driver with attention supports [8]–[12]. In the study conducted by Lindgren [13], drivers' performance using an integrated advisory ADAS display were compared with warnings of a critical character only. Results showed that drivers followed with safer distances when they received advisory information rather than critical warnings only. In Stanton's study[14] , standard brake light displays were compared with a graded deceleration display while the lead vehicle varied its deceleration magnitude and ramping behavior. The results showed that a graded system produced more accurate behavioral responses during deceleration than a standard brake light display. Fagerlönn's study [15] compared three strategies of early warnings in sound modality (radio panning, radio level and mild warning sound) to critical warnings. The results revealed that a graded auditory signal successfully notified the driver more than warnings. In addition, drivers had relatively few inappropriate responses or misses with graded signals. Naujoks carried out a series of studies[16][17] that explored the effectiveness of advisory information in different timing scales and information specificity. The results underlined that early advisory information has more positive effects on driver performance than late warnings when surprising situations occurred.

These studies underline the benefits of providing drivers with advisory information; however, they primarily focus on drivers' reactions and signal designs of advisory warning. What information drivers actually need under different traffic contexts has not been well addressed and is important so as to extend our knowledge on drivers' requirements cross-regionally.

1.3 Our concept

The drive process can be divided into three phases according to Summala [7]; comfort, safety and conflict zones (see figure 1). Drivers will mostly stay in the comfort zone where no potential traffic hazards are involved. In this phase, drivers remain confident and comfortable. As soon as potential hazards occur, a driver will require extra attention to monitor the situation; if the driver doesn't perceive the hazard in time and take correct action, the safety margin will exceed and the driver will potentially lose control of the situation.

During different driving stages, a driver requires different information from ADAS. In the comfort zone, a driver's goal is to gain a good awareness of the traffic around them. Therefore, non-intrusive traffic information should be provided to help drivers maintain a good awareness of the traffic flow. When potential hazards enter the safety zone, the advisory information should be able to direct attention to the right information sources and suggest a proper response to the potential hazard. If this does not occur, the system should alert the driver or carry out other interventions.

Instead of warning the driver in a later phase when the situation has become critical, our approach is design an advisory traffic information systems that present continuous non-intrusive information of surrounding road users from comfort to conflict zone (the green and amber zone in figure 1). Through the information support in these three stages, the driver will be able to gain a good prediction of the traffic situation and avoid entering the conflict zone or warning situations. The functional purposes and the driver's goals in different stages are summarized in the figure 1.

Figure 1. Functional purposes and the driver's goals in advisory traffic information systems

1.4 Objectives

The aim of this thesis is to gain better insights into cross-regional adaptive design on advisory traffic information systems. In this thesis, visual and auditory modalities were studied according to the predefined scope of the research project. Four research questions are studied:

- RQ 1: What traffic information do drivers require from 3D Auditory Advisory Traffic Information Systems (3DAATIS)?
- RQ 2. What are the similarities and differences regarding information requirements between Sweden and China?
- RQ 3. How does Visual Advisory Traffic Information System (VATIS) influence drivers' performance?
- RQ3. Do Swedish and Chinese drivers behave differently when driving with VATIS? And why?

1.5 Delimitations

In this project, ATIS only focused on presenting information regarding different road users. Infrastructures, landmark, traffic signs, and the capabilities of sensor technology were not studied within the research scope. The design of visual information modalities was based on the previous studies in the author's research group. In previous work [12, 17, 18], design persona, storyboard and requirements were investigated with visual information modality. Therefore, in this thesis, the information requirement study was only carried on the auditory modality.

Cultural differences were explored between Sweden and China. Firstly, these countries were chosen due to their large differences of traffic characteristics and driving styles. Secondary, the research group is based in Sweden and has close cooperation with Chinese universities, which made it feasible for the author to conduct studies with these two driver groups.

2. Situation awareness in driving

Situation Awareness (SA) has been presented as a fundamental contributing factor in decision making in dynamic systems[20]. There are three universally accepted definitions of SA theory.

- The three-level model introduced by Endsley [22] describes SA in three hierarchical levels (perception, comprehension and projection).
- The perceptual cycle model suggests that SA remains through the interaction between the person and use context, and SA includes the cognitive processes and the continuous updating of SA [20].
- The activity theory model sees SA as an individual's conscious dynamic reflections on the orientation activities in the situations [21].

Among these theories, Endsley's three-level model is widely applied in the field of vehicle safety and it is also adopted as the theoretical framework of the present thesis. According to the definition, SA is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [19]. See figure 2 below.

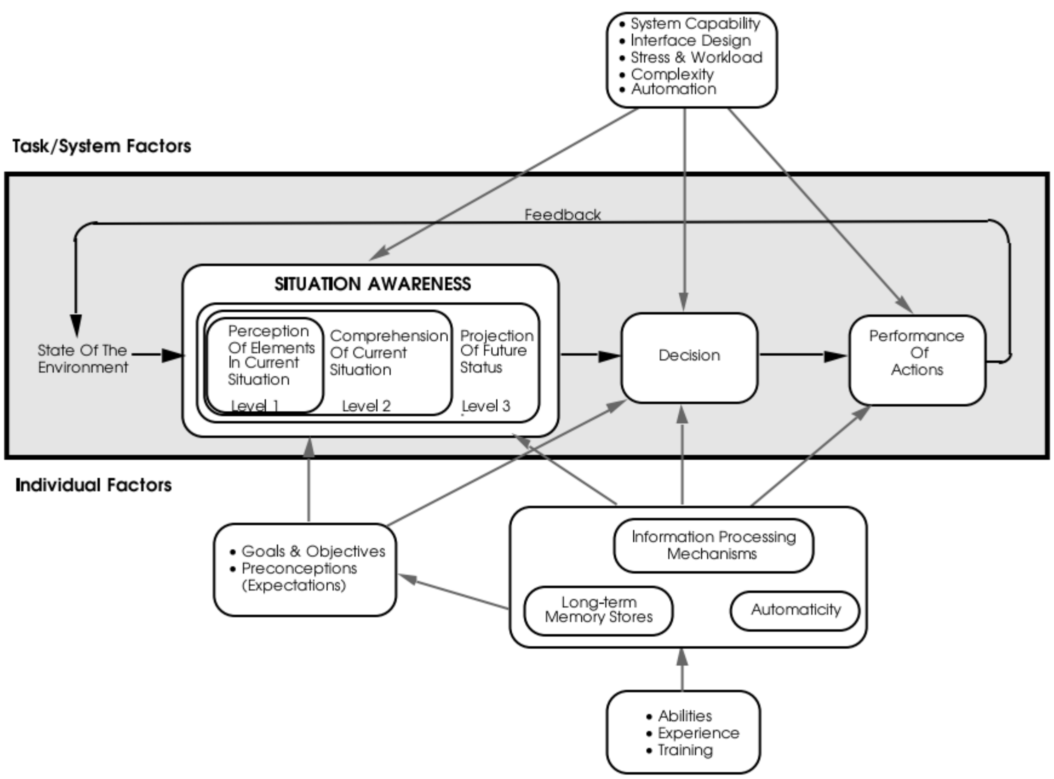


Figure 2. The three-level model of SA [19]

In a driving context, SA can be reflected in three levels.

- Level 1: Perception of elements in the current situation. The driver perceives road conditions, traffic signs, and the movements of other road users (i.e., pedestrians, drivers, cyclists, etc.) in relation to her/his vehicle.
- Level 2: Comprehension of the current situation. The driver comprehends the current state of her/his own driving through combining, reasoning, storing and retaining perceived information. Then the driver synthesizes the information and identifies some potential hazards that she/he should heed based on his/ her personal goal.
- Level 3: Projection of future status. The driver forecasts the development of the hazards in relation to her/his vehicle. When information on all these three levels is available, the driver can anticipate the situation and make the correct decision in advance, in which case warnings and critical signals can be avoided.

A number of recent studies have explored SA in different aspects of the vehicle safety domain: driver attention and distraction in relation to SA[22][23], SA with secondary task[24] and road users' self-assessment of SA[28]. Particularly, two studies have attempted to provide situational information to the driver to enhance SA [29] [30]. In general, these studies recommended to provide the driver with the upcoming road and traffic situation and informing in advance if a highly demanding driving situation is imminent (e.g. approaching a traffic jam, approaching a sharp curve). This will help drivers make the decision of when it is appropriate to direct attention away from the driving task and when it is not.

Together with the development of SA theory, a number of SA measurement methods are established, Salmon et al. has reviewed and summarized the common applied SA measurement methods in[31]. The most two widely deployed methods are Situation Awareness Global Assessment Technique (SAGAT) [32] and the Situational Awareness Rating Technique (SART) [33]. Both methods use subjective feedback regarding SA which focuses on what information the drivers are able to extract from their environment. Beside drivers' subjective assessment of the situation, a number of different approaches, including physiological measurement, performance measures (driving behavior and performance) and secondary task measures are employed [31][32][34].

2.1 Conclusion regarding SA in driving

In this thesis work, the focus is on driver SA with regard to safety-relevant road users in the traffic environment. Providing upcoming road user information on three-levels of SA will assist the driver to foresee the potential hazard, anticipate and respond to the conflicts in a prepared manner. Moreover, to gain a correct SA, the cognitive workload for comprehending the information cues will act as an essential factor in a driving situation. If the information doesn't match with a driver's mental model, the driver will perceive the information as a false alarm or may take too long to understand the information. Thus, the first step in this thesis is to understand drivers' requirements on advisory information supports under different traffic situations.

The SAGAT and SART methods are normally used to measure SA on the informational attributes at various states of a situation. In practice, it involves freezing the experimental scenario numerous times and asking the participant's subjective feedback. This approach is inconsistent with naturalistic driving. Since the focus of this thesis is to understand drivers' requirements and responding behavior to an advisory information system under a normal driving situation, SAGAT and SART measurements have not been applied here.

3. Information modalities

Three modalities are commonly used in Human Machine Interaction (HMI) design: visual, auditory and haptic. Cognitive psychology studies have pointed out that different modalities have their own specification and are suitable for presenting specific information and differences in human reaction time to different modalities. For instance, human reaction time to visual stimulation is about 200 ms and 150 ms to auditory stimulation, while to haptic stimulation it is about 700ms. A right modality can help drivers to detect a hazard object faster, but an inappropriate modality can increase the cognitive workload and reduce acceptance of the information system.

3.1 Visual modality

Driver information presented visually has both advantages and disadvantages [34]. Graphical visual displays allow operators to mentally zoom in and out of the displayed area in a convenient way. Some human factor guidelines have emphasized that warning information should be presented pictorially[35]. In early studies, Zwahlen [36] investigated the safety issues of an in-vehicle visual information display; examining the visual, safety and performance aspects of operating a simulated touch-panel display while driving at a constant speed along a straight road and keeping lateral lane position. Results showed that introducing complicated in-vehicle displays or controls that require eye fixations of several seconds could raise serious problems. Alvarado Mendoza et al. [38] proposed an advisory display based on ecological interface design. This display provided drivers with visual information about the surrounding environment including how other vehicles' behaviors corresponded to the driver. The driving simulator study results showed that continuous visual information presentation in the advisory display could be a good complement to the critical warnings.

Drivers depend largely on visual modality; over 90% of driving related information is perceived visually. In addition, visual warning information shares the same cognitive resource as the driving task, so drivers may experience attention overload [37]. Thus, there is a tendency to develop more pre-warning visual information and other modalities that can be used to support drivers’ attention and present driving-related information. A simulator study was conducted by Liu [38] to compare younger and older drivers' ratings of workload and performance of navigation and identification of vehicle or road hazards tasks when simple or complex advanced traveler information was presented visually only, aurally only or by multimodality (visual and auditory) display. For all participants, both the auditory and multimodality displays produced better performance in terms of response times, total number of correct turns and subjective workload ratings than those of using the visual-only display. The visual display led to less safe driving, because it imposed higher demands on the drivers' attention.

3.2 Auditory modality

Auditory displays can be superior to visual displays in presenting information in vehicles. Recent studies have demonstrated that auditory information improves safety in driving, shortens response time, enhances accuracy and increases drivers’ SA [40], [41]. Using auditory information presentation to offload the visual channel could have an impact on driving efficiency as well, especially when visual sensory information is degraded, for example, information in a blind spot. A number of studies on 3D audio application have proven that auditory information complements visual directional information effectively [42]–[44]. There are several advantages of auditory modality, for instance, omni-directionality, quick perception and intuitive sound localization ability.

It was recently demonstrated that auditory looming warnings (sounds whose intensity increased as the distance between the driver's vehicle and the lead vehicle decreased) resulted in faster brake response time [45]. Looming warning signals are informative to the driver because they take advantage of natural mapping: as a sound-emitting object approaches an observer, there is an associated increase in sound intensity and the rate of change of intensity will be related to the time to collision (TTC), signaling urgency [46]. Studies show that auditory looming and its visual analogue provide very powerful signals to the human perceptual system and that they also capture attention [47]. Gray carried out a study where participants experienced four non-looming auditory warnings (constant intensity, pulsed, ramped, and car horn), three looming auditory warnings (veridical, signals shorter than actual TTC time, signals longer than actual TTC time) under a no-warning condition. The results showed that veridical looming and car horn warnings had significantly faster brake reaction times compared with the other non-looming warnings (by 80 to 160 ms), however the number of braking responses in false alarm conditions was significantly greater from the car horn. Looming auditory warnings produce the best combination of response speed and accuracy [48].

Advantages like omni-directionality, quick perception and intuitiveness that support our natural sound localization ability can be applied to vehicle interaction design, although it is necessary to be aware of some drawbacks with sound design as this is so crucial in the auditory warning. Bad sound design will result in some sounds being annoying[49] or otherwise harmful, particularly highly urgent or high volume warnings that could distract, harm or confuse the driver [50].

3.3 Haptic modality

Although haptic modality is not the focus in this research, it’s still interesting to know what design possibilities exist with other modalities than visual and sound. Using haptic modality to present information and warn the driver has been getting more attention recently and applied to vehicle interaction design [51][52]. A tap on the shoulder is intuitive and almost part of our everyday communication, and most current tactile displays mimic this. The “tap on the shoulder” is simulated by causing a stimulation of the skin where the perception of skin stimulation reveals a relationship between the skin and the outside world. The skin delivers important information about the surrounding environment, which is important for many manipulation and exploration tasks by a dynamic interchange with our autosenses [53][54]. It is a highly detailed and sensitive sensory organ with a temporal sensitivity close to the auditory system. This, in combination with the receptors of the skin being spread over a large area, makes it suitable to receive information related to orientation and navigation. An example of such a design is setting the vibration on the steering wheel for lane departure warning. As discussed earlier, people take longer time to react to haptic stimulation. Therefore, it is not likely that this modality will be used for critical information presentation.

3.4 Conclusions regarding information modalities

Studies have shown that visual warnings are not optimal HMI design approaches in critical situations. The pre-warning and auditory information can be a complementary design for solving current problems with visual warning. According to the multiple resource theory, in a heavily loaded visual display environment an auditory display will improve time-sharing performance [34].

Visual and auditory modalities are well-established information presentation modalities, so are used in this thesis work. For safe driving, short auditory information combined with a visual display might optimize drivers' perception and cognitive performance. Multimodal modality will be explored and studied in the next step of this Phd study. Haptic modality is not included in the scope of the project, but will be worth investigating in future projects.

4. Traffic differences between Sweden and China

As previously stated, most ADAS is designed based on western markets. It functions optimally when traffic infrastructure is well designed and road users are obeying regulations. Hence, the implementation of ADAS has a notable success in mature markets, for instance Europe, US, and Japan. In comparison, the development and sale of ADAS is not ideal in emerging markets such as China. This is probably due to several factors. One study showed that only 14% of respondents could clearly describe the functionality of their own ADAS in China [54]; furthermore, the design of ADAS might not be able to handle the inconsistent road infrastructure and the irregular behaviors caused by large numbers of inexperienced drivers prevalent in that country.

Sweden is a mature industrial country with over 100 years of car driving history, and is one of the safest countries regarding road transportation. In 2011, traffic accident record, in which 314 persons died and 4500 were severely injured [55]. Safety awareness among road users and transportation system design parties in Sweden is very high; "vision zero" has been set as its national goal for 2020 [56]. By contrast, in China the automotive industry only started booming in the 1990s and has been gaining momentum since. Its total number of motor vehicles increased from 1.59 million in 1978 to over 120.89 million by the end of 2012 [57]. Of these, the number of private car owners increased by 22.8% in the year 2012 alone. This figure indicates that the composition of the driver population has quickly changed from a majority of professional drivers to one of private drivers with short driving experience [57]. At the same time, most drivers are the first generation of drivers in their families, which means none of their parents know how to drive. The other road users, such as pedestrians or cyclists who do not drive, may not have any experience about driving, or understand how vehicles may behave on the road [58]. Corresponding to the rapid growth in number of vehicles and driver populations, 65,225 road traffic deaths happened in China in 2012 [59]. Studies [60][61] showed that the major factor contributing to these accident numbers was violations of traffic regulations.

The differences of driving patterns between Sweden and China are extreme in multiple dimensions and imply that the HMI design of ADAS for drivers in mature markets may not necessarily be optimal for other emerging markets [35] [36]. Lindgren [48] points out that a system considered useful in one country can be seen as almost worthless (or even harmful) in another, and system settings feasible in one part of the world may not be suitable on the other side of the globe.

4.1 Conclusions regarding traffic differences between Sweden and China

As mature markets are the most dominant automotive markets, the development of ADAS is generally based on traffic situations and drivers' needs in those countries. An increasing amount of research has recently been published on the technical aspects of ADAS development, with many of these publications coming from China [62]–[64]. However, there is little information on attempts to understand the traffic situations and driver behavior among Chinese drivers, which creates a problem in that country and suggests an even bigger problem when designing products for a global market. The key to successful design for global use is an understanding of how requirements differ around the world [65]. This may be particularly true for ADAS since not only the rules of the road, but also contextual environments and driver behavior may vary significantly from country to country and have a notable influence on the attitudes and behaviors of drivers.

5. Summary of studies

Four studies were conducted in this thesis work; each study carried out to answer one research question listed in section 1.4.

Study 1 aimed to understand Chinese drivers' attitudes, information requirements and prioritization strategies towards 3DAATIS under identified traffic scenarios.

Study 2 was a duplicate of study 1. The same experimental settings were set up in Sweden. The aim was to compare Swedish drivers' information and prioritization strategies with those of Chinese drivers to find out the similarities and differences.

Study 3: In this study, two interfaces of VATIS were designed and evaluated in a driving simulator. The aim was to investigate how VATIS effects drivers' performance and attitudes towards VATIS before and after the use.

Study 4: The experiment settings in Study 3 were duplicated in this study. This study was aimed to compare the different behaviors between Swedish and Chinese participants when driving with VATIS. The results will provide a reference base of how VATIS design based on Swedish drivers' inputs was perceived by Chinese drivers.

5.1 Study 1

Aim

The purpose of this study was to collect Chinese drivers' requirements on how to support their driving safety by 3D sound; that is to design a 3D Auditory Advisory Traffic Information Systems (3DAATIS) to inform the drivers about other road users (i.e. other cars, pedestrians etc.); their location, movement, and distance in relation to the drivers during a normal drive. The 3DAATIS intends to present the traffic situations in an intuitive way, which supports an efficient understanding of traffic information.

Methodology

Six focus group discussion sessions with 25 participants were conducted in China. To understand drivers' needs in different driving contexts, over 100 hours of naturalistic driving and near crash/crash video records from both Sweden and China were observed. Four clips were selected to represent four situations: highway, roundabout, city road, and residential area. From each clip, four to five traffic scenarios were pointed out and discussed thoroughly among the participants. Each traffic event represented the characteristics of each traffic scenario; for instance speed limits, road conditions, and the mixture of road participants. Four types of road users were identified from the clips: pedestrians, bicyclists, motorcyclists, and vehicles.

The experimental settings in this study aimed to mimic a realistic driving environment by showing real time traffic footages and stimulating 3D traffic surround effects. The prototype system used a 3D surround sound system to present traffic information in terms of road user types, location, movement, and distance to the driver's own vehicle. The software of Soundtrack Pro was applied to create a 3D sound environment corresponding to the selected traffic clips. In the prototype, we reproduced the traffic situations to the driver; additionally, the 3D sound information enhanced the information regarding the road users which were close or were in some other way a potential danger to the driver. The sound types applied in the prototype were auditory icons and synthesized sounds. Each sound category contained six sounds mapped to different road users.

The experiment included three sessions: 1. Sound sample matching: The participants were asked to match both auditory icons and synthesized sounds with a list of road users. Each sound sample was played twice in a randomized order. 2. Spatial response test: To test whether participants understood how the spatial information worked in the system, different spatial positions (front- right, front centre, front-left, rear-right, right-center rear-front) and sound movements were played to the subjects one by one. 3. Focus group discussion: For each discussion group, 3DAATIS was demonstrated with four traffic clips with both sound types in a random order. After each demonstration, a predefined semi-structured questionnaire was administered. The questions were related in several aspects: information requirement, opinions about sound and interaction design. From each scenario, four to five traffic events were pointed out and discussed thoroughly among group members. The whole discussion session was tape recorded for data analysis. To avoid the subjective interpretation bias of focus group discussion data, two PhD students were involved in the entire data analysis process.

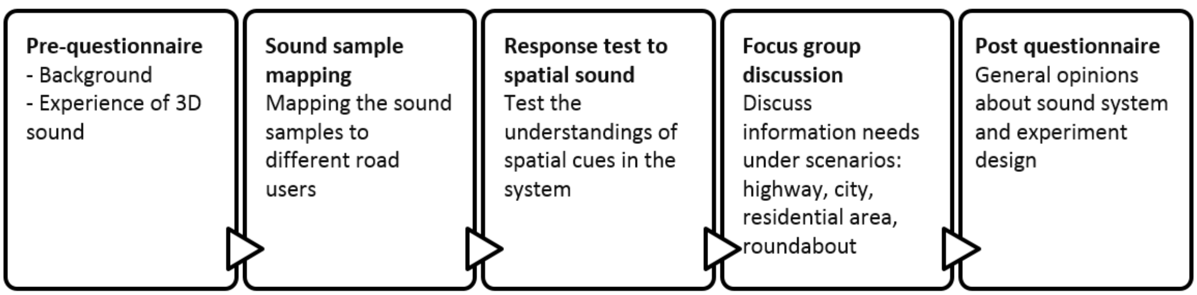


Figure 3 Experimental procedures

Results

The results showing the matching rate of both auditory icons in comparison with the synthesized sound have confirmed Fagerlönn's [50] findings that use of sounds that have a natural meaning in the driving context are easily associated with their intended information, and drivers have a higher acceptance of meaningful sound. Another interesting result is that many subjects rated the spatial effects as a very good feature for getting attention and for allocating traffic information. In addition, it is promising that almost all the subjects perceived the spatial information correctly in the orientation response test.

Regarding information requirements, driving experience and context have strong influences on drivers' information needs. Experienced drivers were leaning towards getting only critical information, whereas most novice and some female drivers instead required that the system should instruct them during the entire drive with detailed traffic information. Due to the high density of Chinese traffic, especially when speed is low or during rush hours in traffic jams, the sound information should only present urgent information. In addition, drivers expressed that they would require more information support in unfamiliar contexts than everyday routines. Different information prioritization requirements were shown on different regions around the car, for example blind spots, side and rear area received high interests of information request; however information from the front zone was conditionally required only when irregular or extreme situations happen.

Contribution

Using 3D sound to present traffic related information is still novel in the field of ADAS, but the results of the present study have shown a strong preference from the drivers. Many auditory signals implemented in vehicles today are coupled with visual information, where the auditory information is mainly used for attention grabbing and the visual information provides the detailed information. But sometimes it actually increases drivers' cognitive workload when they switch between modalities. Thus, the results of the present study underline the potential of utilizing the characteristics of 3D sound and auditory icons to present situational information cues rather than only attention directing.

The results of Chinese drivers' information requirements showed that subjects have different prioritizations concerning the different zones around car. In normal traffic situations they are more interested in information where visual perception has disadvantages, such as from the blind spot, side and rear zones. One of the design implications is that auditory information should complement the visual perception to enable the driver to have a complete perception and sensation of the driving environment, rather than only reproduce or enhance the information that visual perception can cover.

The results also emphasized three information design filters: Speed, familiarity of the context and the level of driver experience.

5.2 Study 2

Aim

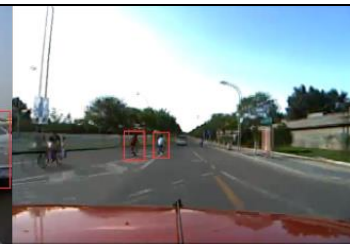
In the field of ADAS design, there has been little user study on understanding the differences in information requirements between mature and emerging markets from drivers' perspectives. The purpose of the present study was intended to fill the gap. It focuses on understanding the differences between Swedish and Chinese drivers on traffic information requirements for designing 3DAATIS which will provide drivers with advisory traffic situational information.

Two research questions are investigated in this study: first, what are Sweden and Chinese drivers' attitudes towards 3DAATIS? Second, what are the similarities and differences on information requirements between Sweden and China?

Methodology

A total of 13 focus groups were included in the study; seven Swedish focus groups (19 male and 5 female) and the six Chinese groups (16 male and 7 female) conducted in Study 1. This study is a duplicated study from Study 1; the experimental settings and selected traffic scenarios were kept exactly the same in the two countries. Some samples of the situations are illustrated as below.

Table 1: The scenario categories and samples of scenarios

Scenario categories	Samples of scenarios
A. Interactions with a single road user	 
B. Interactions with multiple road users	 
C. Interactions with a single road user in special road situations	
D. Interactions with multiple road users in special road situations	 

Results

The outcomes of the study underlined in general Swedish and Chinese participants' requirements have many similarities. Participants from both groups have expressed high acceptance of the concept of 3DAATIS and significant higher sound design preference on auditory icons than other sound types. Drivers' information prioritization results demonstrate that even though both countries have different traffic situations and driving behaviour, the information needs and prioritization under traffic scenarios category A (only interact with one road user at the time) are very similar. Vulnerable road user information is perceived as a higher information priority compared to motorized road users. This information prioritization requirement correlates more with drivers' own subjective experience rather than with the mental workload of complexity of driving task. Regarding information around the car, generally blind spot information and urgent information in the front zone are appreciated.

However, significant differences between two countries were also observed under scenario categories B, C and D (interact with multiple road users and under special road situations). In this study, three representative scenarios were identified: cut in, hard brake, and entering ramp. Under these typical scenarios, Swedish participants required information from the front side intended to avoid front-rear collision, while the Chinese participants often asked for information not only for the front side, but also from rear and side areas. Under these typical scenarios, Chinese drivers would often take the strategies of changing lanes, or just driving to the side to avoid the conflict.

Contribution

First, the study showed drivers from both groups have a high acceptance of meaningful sound design. Hence, this result emphasizes that when designing the sound cues in 3DAATIS, a sound design that imitates the road users' characteristics and includes the scale of auditory icons and synthesized sound may be an appropriate approach to fulfill drivers' acceptance and reduce annoyance.

Second, the differences found in three typical scenarios show how drivers from different regions expect the system to support them in driving. Furthermore, identified traffic scenarios under scenario category B, C and D provide a starting point for future 3DAATIS design.

5.3 Study 3

Aim

This study aimed to understand how do VATIS influence drivers behavior and performance.

Methodology

Two interface designs of VATIS were developed in an iterative design process. Design 1 displayed only the directional information of road users around the driver while Design 2 presented direction as well as the type of road users. Figure 4 shows an example state of the designs. Four types of road users (pedestrian, cyclist, motorcyclist, vehicle) are identified and if more than one road user is located in a region a multiuser icon is used. The colours yellow, amber and red [51] are used to communicate that a road user is in a specific region, and the specific colour and volume of the colour indicate the level of urgency. As the time to collision (TTC) decreases, the colour changes from yellow to amber and finally to red. The threshold values for the TTC are nine, six and three seconds.

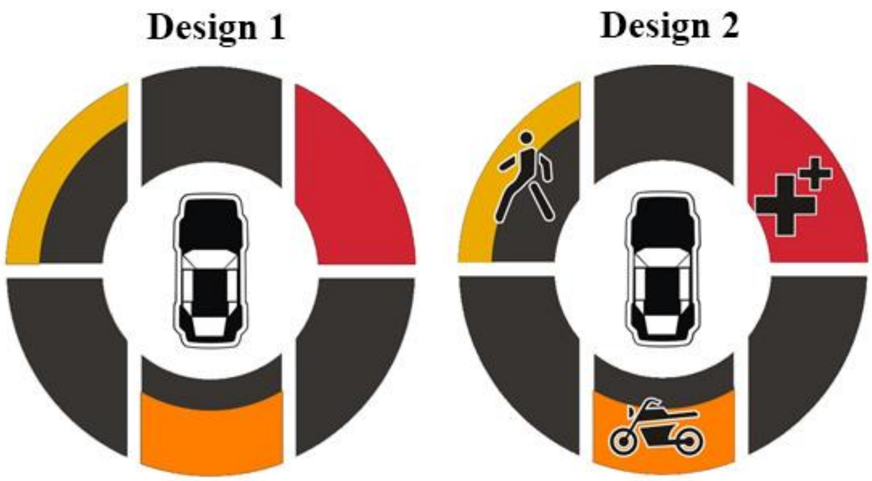


Figure 4. Two conceptual designs of VTIS [These two interfaces were designed by master students Bo Chang and Marshall David under supervisions of Min Juan Wang]

The driving simulator study was performed with 20 participants. After two designs were briefly introduced, a questionnaire asking questions about the designs, including their acceptance before use, was administered. During the test each participant drove the scenario three times: baseline without any display, once with Design 1 and once with Design 2. The participants were given the baseline and two designs in different orders. After driving with both Design 1 and after driving with Design 2, a questionnaire asked the user to evaluate the design and indicate their level of acceptance of the design. After all three scenarios were completed a final post questionnaire asked which design they preferred and why.

Results

After using Design 1, the average score for usefulness increased from the baseline from 0.79 to 0.88 while the average for satisfaction increased from 0.4375 to 0.5875. After using Design 2, the average score for usefulness increased from 1.1 to 1.25 while the average for satisfaction increased from 0.55 to 0.7125. In other words the acceptance of Design 2 was greater than the acceptance of Design 1. When asked their preference of designs, 10% (two participants) had no preference, 30% (six participants) preferred Design 1, and 60% (12 participants) preferred Design 2. These results indicate a strong preference towards Design 2.

Contribution

The results from both Van der Laan's acceptance scale and the participants' preference of designs clearly showed Design 2 as most accepted and preferred. The additional road user type information in Design 2 was more useful than Design 1 despite it being a distraction to some users. The road user type information allowed drivers to more accurately predict and react appropriately to the scenarios.

Using the TTC concept for the prioritization of road users was successful in the study, so is applied in all the zones; however a different information prioritization approach for different regions would also be worth exploring in future studies.

5.4 Study 4

Aim

The purpose of the present study was to find out whether the system developed in Sweden could also be appreciated in China. Drive simulator studies were carried out in both Sweden and China. Two research questions were addressed:

1. What are the differences between Swedish and Chinese drivers' attitudes towards an advisory system in various traffic situations?

2. How does such an advisory system affect Swedish and Chinese drivers' behaviors respectively?

Methodology

The experiment was carried out in both China and Sweden. 25 Chinese drivers (14 male, 11 female, between the age of 27 and 43 years, average driving experience 7 years) and 20 Swedish drivers (11 male, 9 female, between the age of 27 and 42 years, average driving experience 14 years) were randomly selected as subjects. The experimental settings and procedure were maintained the same as in Study 3.

Results

Comparing drivers' acceptance level between two countries, significant effects were observed between groups (Sweden and China). In both Design 1 and Design 2 with road user icons, Swedish participants perceived positive scores on usefulness and satisfaction, while Chinese drivers scored negatively.

In Design 1, the rating results showed that Swedish drivers were most interested in three regions: Front Right (FR), Front Left (FL) and Back Center (BC). In contrast, Chinese drivers appreciated more information on Back Center (BC), Back right (BR) and Back Left (BL) regions. With Design 2, Swedish drivers' preference was similar to Design 1. They still have preference for FR, FL and BC. However, Chinese drivers slightly changed their preference on FR, and FL increased compared to Design 1. Feedback from Chinese drivers showed that they found the pedestrian icon in FL and FR areas really helpful, as it could assist them to anticipate pedestrians' behaviors better.

The results of collision rates showed that the numbers and percentages of critical situations ending in a collision provide convergent evidence regarding safety benefits of advisory information interfaces. Compared with the baseline condition (no advisory interface), driving with an advisory information system reduced the percentage of collisions. In particular, a system with Design 2 reduced the collision rate of 13% in Sweden and 18% in China.

In “CutIn” scenario, drivers’ brake-to-minimum TTC measures the time to collision when a driver first responds to the “cut in” vehicle. The drivers’ brake-to-minimum TTC exhibited statistically significant effects. In Sweden, Design 2 had a statistically significant effect of minimum TTC on increased response time in the scenario where the front vehicle cut in suddenly, $F(2, 58) = 3.9$, $P < 0.05$, in which a 0.48s margin was obtained from the baseline condition. In comparison, Chinese drivers had a statistically significant increased minimum TTC when driving with Design 1, $F(2, 68) = 5.853$, $P < 0.05$, (i.e., from 0,06s for the baseline condition to 3.05s for Design 1 condition).

Contribution

The acceptance result suggests the system designed in one region has great potential to fail in another region. Participants’ subjective results emphasized that a cross-regional adaptive design is especially necessary when introducing a new advisory information system from a market where the traffic flow is low and traffic regulations are well obeyed among road users, into new markets such as China, where the traffic density is high and regulations are badly followed.

The drivers’ preferences in different regions showed that driver behaviors and strategies when handling different situations have huge influences on information requirements. The drive performance results also show that the two designs have assisted Swedish and Chinese drivers differently due to different driving strategies and habits.

6. Discussions

6.1Methodological considerations

During the work presented in the thesis, a method of using naturalistic driving films as design tools was explored and developed. In addition, the method of selection and categorization of these films was developed to fulfill the design goal of a cross-regional adaptive advisory traffic information system.

- Using naturalistic driving videos as design means in ADAS design procedure

Recently, many naturalistic driving projects have been conducted, such as the 100-Car Project (Naturalistic Driving study in the United States) [67], and similar projects like euroFOT (European Field Operational Test) [68], SeMiFOT(Sweden Michigan Naturalistic Field Operational Test) etc. The report [67] indicates that those projects provided vital exposure and pre-crash data for understanding causes of accidents. The applications of the naturalistic driving data have mainly focused on the evaluation of risky driving behavior and crash risk, calculation of relative risk of engaging in secondary tasks, and evaluation of driver response to traffic related information.

However, although those naturalistic driving data are invaluable for the design and evaluation of ADAS, only limited studies have applied naturalistic driving videos in the early stage of ADAS development. The driving videos from the naturalistic driving database have a continuous view into the happenings in and around the vehicle; providing very good resources for the designers to gain an inside view of the natural driving context, as well as the driver's behaviors and needs under different situations. In the design process, engineers would normally apply different scenarios or storyboards to build up the common understanding of particular situations[69]. These stories would contribute to a larger narrative involving an entire design team and project members. The real-time recorded naturalistic drive films can act as the scenarios and storyboards, and the design team can therefore build up a common ground for understanding design constraints and problem domain which need to be considered. It can also let the designers evaluate the proposed design and its positive or negative impacts. According to Langford, the problems or design deficiency identified by the focus group provides a tangible baseline that can lead directly to a range of solutions, and at the same time, the new or modified set of user requirements might also be identified[70].

In the present thesis studies, naturalistic driving films were used as design means throughout the entire design process (see figure 4). During the focus group discussion, naturalistic driving films provided an opportunity for everyone in the focus groups to get the same view of the traffic situation. During prototype design, those naturalistic films were applied as dynamic storyboards to facilitate the user interface design and evaluate the validity of designs under each different traffic scenario. Based on the characteristics of the real scenarios, the drive simulator's environment and scenarios were programmed.

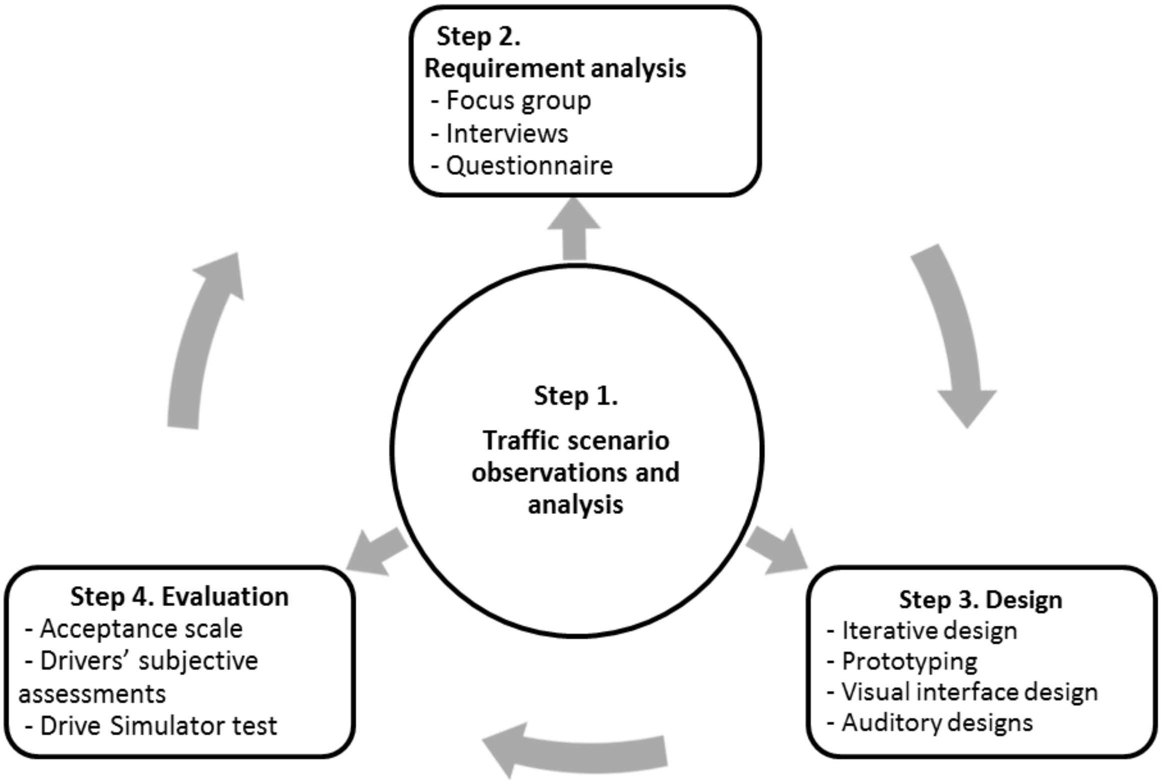


Figure 5 Using Naturalistic Film as design tool throughout the entire design process

When applying naturalistic driving films into the design process, there are several aspects to be taken into consideration. Firstly, in selection of naturalistic films, the selection should align to the design goals and interest, for instance, the approach to select scenarios for ATIS is quite different from that used in selecting warning systems. Detailed discussion of this can be found in the next section. Secondly, consideration should also be given to how to use naturalistic films as design means efficiently. Making indication markers on the events or road users in the video will help participants or designers to pay attention and pick up important information cues while watching films. Developing a low-fidelity prototype of the concepts would be an extra help to bring the benefits of assisting participants or other designers in the team to get a tangible feeling of the concept design and design constraints.

- <u>The method of scenario categorization</u>

There are two established traffic scenario categorization methods in literature; one categorizes a scenario based on various driving environments including different types of road, speed and ambient lightings, etc. Another method is event based analysis (EBA) in which the basic principle is to identify events thought to be predictive of crash involvement, for instance, a critical event into a lead vehicle where FCW triggers. In EBA, the focus is on critical events at the operational decision level [71] that a driver executes within a second. Under such a situation, drivers only interact with one road user that affects their driving performance.

However, an advisory traffic information system provides non-critical information on the tactical level in which the driver's reaction takes place over seconds. Under such situations, drivers often interact with more than one road user. From the results of this thesis, categorizing traffic scenarios according to the number of road users in the situation works better for the purpose of traffic advisory system design (See figure 5). In this thesis, the traffic situations were categorized into 4 groups: A. interaction with a single road user, B interactions with multiple road users, C interactions with a single road user in special road situations, D interactions with multiple road users in special road situations.

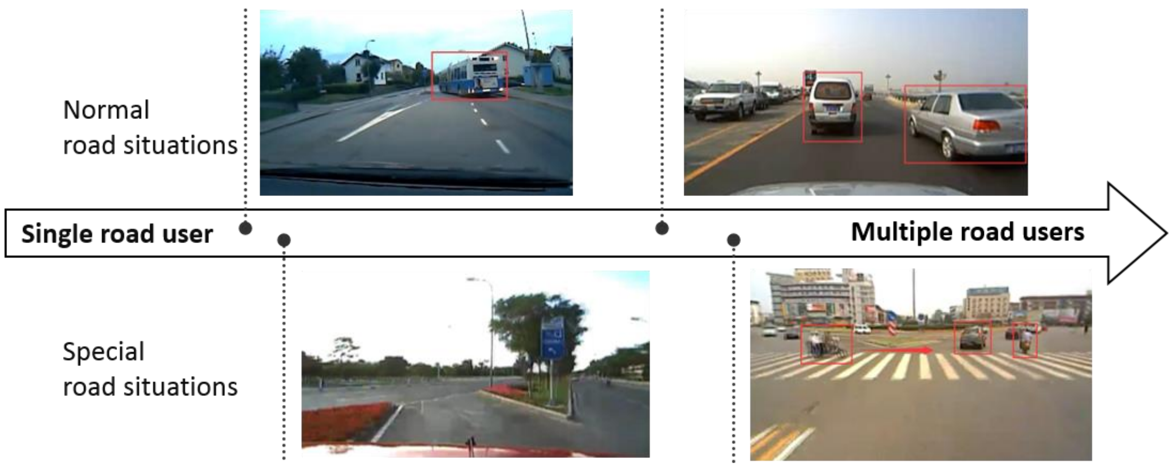


Figure 6. The scale of interactions with different numbers of road users

Taking Swedish and Chinese traffic situations as examples, in Sweden, most traffic situations are on the left side of the scale, in which traffic density is comparative low. In China, the general traffic situations fall onto the right side of the scale where drivers often interact with multiple road users simultaneously. The results from studies 1 and 2 indicate that drivers' information requirements are quite different under categories B, C, and D between Sweden and China.

- Simulator limitations

The starting point of study 3 and 4 were to examine how drivers react to an ATIS in normal driving. So when we produced the simulator test scenario, we tried to simulate the real normal traffic flow, which leaded to time intervals between each event were very short, and sometimes the two events were even connected in series. There were more than one event happened simultaneously, we could not identify the true reaction to the events in the simulator data. It created a huge complexity for the simulator analysis.

6.2 Drivers' information requirements

RQ 1 and 2: What traffic information do drivers require from 3DAATIS, and what are the similarities and differences between Sweden and China?

Our hypothesis was that the difference on information requirements between two drivers groups is large, due to different drive context, behavior and habits. However, the results showed us the similarities between these two extreme different groups is greater than difference. Swedish and Chinese participants have similar preference in the design of system and information requirement when they interact with a single road user (scenario category A). However, clear differences on information requirements was identified under situations when they interact with multiple road users (scenario category A, B and C).

- Similar design preference

Swedish and Chinese participants have much in common in terms of sound mapping rate, sound type preferences, and attitudes towards the design of 3DAATIS. From the overall sound mapping results, participants in both countries scored at a high accuracy with auditory icons and low accuracy with synthesized sounds. This result agrees with the findings of Fagerlönn [71] that meaningful sounds in the driving context require considerably less cognitive resources and higher accuracy of interpreting the events. One unexpected result was observed in the mapping rates; the cyclist event had comparatively low mapping results with its auditory icon but noticeably high mapping rates (more than half the group in both countries) with its synthesized sound. The reason was that the pitch of the cyclist auditory icon was too high, and participants failed to associate its acoustic characteristics with a bicycle bell. With the synthesized sound, the participants perceived the intuitive similarities between the timbres of the cyclist synthesized sound and a bicycle bell. In addition, several participants stated that the cyclist synthesized sound was pleasant to hear. The results of the sound mapping rates also emphasize that auditory icons have the advantage of carrying an inherent meaning and require little learning. Still, this meaning may not be same to everyone. As the results indicated, the auditory icon for the cyclist reminded some participants in this study of a bicycle bell, which the designer intended, while others interpreted it as a cowbell.

Regarding the attitudes towards 3DAATIS, both Swedish and Chinese drivers believed that situational auditory information could provide a good understanding of the traffic dynamics. General awareness of what is happening in the direct vicinity of the car (e.g., a bicycle in the right blind spot at an intersection) provides the drivers with a more accurate idea of the situation, so dangerous situations can be prevented or at least anticipated. In this study, the 3DAATIS prototype presented every road user's information to the participants to set up discussion points; based on the participants' feedback, information prioritization and filtering are the key factors to achieving a successful system.

- Information requirements

Drivers' information prioritization results demonstrated that even though both countries have different traffic situations and driving behaviours, the information needs and prioritization in traffic scenarios in category A (interaction with one road user at a time) are very similar. Information about vulnerable road users is perceived as a higher information priority than that of motorized road users. Marina [72] showed that vulnerable traffic participants have the lowest priority when searching for hazards; but for information support, drivers require more assistance for situations with vulnerable road users than for the complex driving task. Regarding information around the car, blind spot information and urgent information in the front are generally appreciated. While driving, visual attention is still the primary information source channel, and auditory information is considered to be a supplementary information source to compensate for the shortcomings of the visual channel.

However, the differences between the two countries was obvious in traffic scenario categories B, C, and D (interaction with multiple road users and under special road situations). Swedish participants require information only from the front, while the Chinese participants often seek for information not only from the front but also from the rear and side areas. One possible explanation is that drivers in Sweden respect and follow traffic regulations; they trust and rely on other drivers to also obey the rules. Conversely, in China, as in other industrial developing countries with high-density traffic, road users (not only the driver but also other types of road users) try to fill all possible space on the road. In such situations, drivers must not only consider the traffic regulations but also must coordinate with one another. Therefore, each driver needs to take care of not only the front side but also every side around the car to be able to manoeuvre in traffic. The typical situations of cut-in, hard brake, and ramp entry were identified in the study. Chinese drivers would often take the strategy of changing lanes or driving to the side to avoid a conflict. This is understandable because if they brake sharply, it may result in a high probability of rear-end crash or create a series of conflicts among many road users behind the vehicle. The differences found in these scenarios implied how drivers from different regions expect the system to support their driving. To design a successful driver support system, more driver requirements and observation studies of scenario categories B, C, and D are needed.

6.3 Driver behavior when driving with VATIS

RQ 3 and 4. How does Visual Advisory Traffic Information System (VATIS) influence drivers' performance? Do Swedish and Chinese drivers behave differently?

- Drivers' subjective feedbacks after driving with VATIS

After participants drove with a VATIS, subjects were asked to select which sectors around the car they perceived useful. The results showed that Swedish and Chinese drivers have different views on the priority of the information in different regions around a car. For both Design 1(only directional and risk levels information were presented) and Design 2 (directional, types of road users and risk levels information were presented), the Swedish drivers have high priorities for information in the Front Left (FL) and Front Right (FR) zones. In Sweden, the drivers are educated to pay more attention to their front side. If they have conflict with road users in the front of the vehicle, they will take the responsibility for the consequence. Therefore, Swedish drivers have shared "knowledge" that when a vehicle in front is changing lanes, the vehicle in the back should always give way to the front ones. When drivers plan to switch lanes, multiple potential hazards may occur in the FL and FR areas, and the information presented in the advisory system can provide the necessary information in advance allowing extra time to plan for the maneuver. In the simulator test in studies 3 and 4, there were several scenarios with pedestrians walking into the street from road shoulders, or cars on the roadside starting up when the driving car was approaching. These specific scenarios seldom occur in Swedish traffic. Under such unfamiliar contexts, advisory information in the FL and FR regions may provide helpful assistance by leading visual attention towards potential hazards. This results have confirmed the findings from study 1 and 2.

In comparison, Chinese drivers have higher interests in the BL and BR regions. This finding aligns with the results in Studies 1 and 2. In all the studies (1, 2, 3 and 4), Chinese drivers remarked on the blind spot information in Back Left (BL) and Back Right (BR). In particular, they desired this information under changing lane situations. In the simulator test, when a vehicle cuts into driver's lane, Chinese drivers often attempt to seek alternatives, for instance, changing to another lane or speeding up instead of braking. This could be a good explanation of why presenting information on the BL and BR regions is important.

We have also found that Chinese drivers are less interested in the information from the front regions in Design 1. In China, normally the traffic flow is in high density and mixed with different types of road users. It is predictable that there may always be some information clustered in the interface in a Chinese traffic situation. Chinese drivers may perceive the levels of urgency differently from Swedish drivers. Similar findings have been reported by Lesch [56] who reported that Chinese drivers perceive less urgency compared with American drivers. Another possible reason for lack of interest in the front zones might be that when the display only presents directional information, the participants perceives the hazard on display first, and confirm the existence of hazard and comprehended by eye searching, then decided to respond to it. Such cognitive process is not appreciated under complex and urgent situations. Under typical Chinese traffic situations such as a pedestrian running into street or vehicle cutting in to the lane, an immediate response is required. Thus, directional information in Design1 on frontal zones was not appreciated by Chinese participants. An interesting shift on regional information requirement was found in Design 2, where Chinese participants increased their information preference in the front zones because of vulnerable road users information was displayed. As mixed traffic is a common situation in China, providing vulnerable road users information can help drivers enhance their driving comfort and applied different driving strategies, this assumption actually has been approved from participants' simulator drive results.

- Drive performance

Overall, the results of drivers' performance in simulator studies showed positive effects with both Swedish and Chinese drivers. The results for the collision rate indicate a clear advantage of using advisory information systems when driving in critical situations. This also extends the results of J.Lee and J. Hoffman [73] where graded warnings provided a greater safety margin, meaning that a graded approach may provide an additional safety benefit because it may reduce rear-end collisions induced by sudden braking in response to false warnings.

Comparing reaction time to the baseline condition where no advisory system was displayed, Swedish drivers gained 0.48 second with Design 2; for the Chinese group, with Design 1 the drivers responded to the events 3.04 seconds earlier. A possible reason is that Swedish drivers were not so experienced with mixed traffic. Thus, receiving road user information from Design 2, they drove more cautiously which helped them better anticipate the situation. The directional information on design 1 didn't succeed to assist them to predict and plan for the situation in advance, therefore, the brake time remained the same as the baseline.

In contrast, in China, mixed traffic is normal and Chinese drivers take different strategies with different types of road users. With Design 2, they might have utilized the road user information to maintain their driving strategies with different road users. In this scenario, design 2 informed the drivers that the coming hazard was a car; therefore, the drivers' safety margin was similar to the baseline condition. However, design 1 only presented a potential hazard coming from the front right direction, which caught a driver's attention but without indicating whether it was a vulnerable road user or not. Drivers knew it is difficult to predict the movement of vulnerable road users so they would rather be more cautious. This result brought up an interesting consideration for designing such advisory systems. Either the system should provide information clues to draw drivers' attention to hazards, or present a full picture of the hazard situation so that the driver can maneuver without checking the real world. How would these two approaches affect drivers' behavior in the long term?

6.4 Design implications

In order to reach a good auditory advisory traffic information design, the sound design quality is very important, good sound design succeed the system, poor design failed the system. The link between traffic situation and auditory information is important; auditory is complemental channel of visual, when every auditory information matches correct with the perception of the situation, the drivers' acceptance rate will be high. In general, it may be difficult to find a suitable match between different events or road users and sounds, the inspiration gained from the cyclist synthesized sound may indicate that a brief synthesized sound imitating road users may be a creative approach to design auditory information in advisory traffic information systems.

Swedish drivers perceived significantly higher usefulness and satisfaction levels than Chinese drivers in general from studies 3 and 4. The users' requirements study, design and usability evaluations of the two interfaces were carried out with Swedish users. Sweden is one of largest markets for active safety systems around the world. Around 20% of the vehicles running on Swedish roads are equipped with ADAS, and most Swedish drivers are familiar with active safety systems as well. This may lead them to have an open mind towards such an advisory system. In comparison, the ADAS system is not popular in China. The traffic in China, as well as many industrial emerging countries, is characterized by high density and mixed traffic. In this traffic situation, it requires drivers to focus their visual attention on the road. It would be extremely dangerous and distracting if an interface required drivers' visual attention monitoring both information displays and road simultaneously. This result suggests that a cross-regional adaptive design is especially necessary when introducing a new advisory information system from a market where the traffic flow is low and regulations well obeyed, into new markets where traffic density is high and regulations are badly followed.

7. Conclusions

The information requirement studies in this thesis showed that the similarities between Swedish and Chinese participants are greater than the differences. For example, they have similar design preferences and information requirements when interacting with a single road user. However, interesting differences were found when multiple road users were involved in the situation, e.g., in *enter ramp, cut in* or *change lane situations*. The driving performance results indicated that advisory traffic information systems assisted Swedish and Chinese participants in different ways due to the different regional driving strategies and habits. Moreover, acceptance results also emphasized that an interface design entirely carried out in one region will likely result in lower user acceptance in another region. Last, bringing naturalistic driving films into different design stages can assist designers identify contextual constraints of the system. It provides a systematic approach to understand a driver's goal and information prioritize strategies in the complex traffic situations. To sum up, cross-regional adaptive designs should focus on specific situations where the regional difference occurred, it can be a feasible approach to a successful global design. In future studies, the acknowledged information requirements should be evaluated in the driving context to examine how Swedish and Chinese drivers apply their driving strategies in a real driving context.

8. References

[1] U. C. Berkeley, S. A. Seshia, and U. C. Berkeley, “User Interface Design and Verification for Semi-Autonomous Driving,” pp. 63–64, 2014.

[2] M. H. & K. A. B. Dick de Waard, Monique van der Hulst, “Driver behavior in an emergency situation in the Automated Highway System,” *Transp. Hum. …*, 1999.

[3] A. Lindgren, R. Broström, F. Chen, and P. Bengtsson, “Driver attitudes towards advanced driver assistance systems – a cross-cultural study,” *Hum. Factors*, no. 2001, pp. 1 – 12, 2007.

[4] F. Chen, C. Giubega, P. Chen, and M. Wang, “Designing an In-Vehicle Advisory System to Support Traffic Awareness,” in *10th ITS European Congress, Helsinki, Finland*, 2014, no. June, pp. 1–12.

[5] E. Hollnagel, “A function-centred approach to joint driver-vehicle system design,” *Cogn. Technol. Work*, vol. 8, no. 3, pp. 169–173, Apr. 2006.

[6] M. Roetting, Y. Huang, J. Mcdevitt, and D. Melton, “When technology tells you how you drive—truck drivers' attitudes towards feedback by technology,” *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 6, no. 4, pp. 275–287, Dec. 2003.

[7] H. Summala, “Towards understanding motivational and emotional factors in driver behaviour: Comfort through satisficing,” in *Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems*, P. C. Cacciabue, Ed. London: Springer, 2007, pp. 189–207.

[8] J. Morrell and M. Ieee, “Design and evaluation of a vibrotactile seat to improve spatial awareness while driving,” *Symp. A Q. J. Mod. Foreign Lit.*, pp. 281–288, 2010.

[9] B. J. C. Mccall and M. M. Trivedi, “Driver Behavior and Situation Aware Brake Assistance for Intelligent Vehicles,” *Proc. IEEE*, vol. 95, no. 2, pp. 374–387, 2007.

[10] C. Ho, H. Z. Tan, and C. Spence, “Using spatial vibrotactile cues to direct visual attention in driving scenes,” *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 8, no. 6, pp. 397–412, Nov. 2005.

[11] B. R. Fajen and W. H. Warren, “Behavioral dynamics of steering, obstable avoidance, and route selection.,” *J. Exp. Psychol. Hum. Percept. Perform.*, vol. 29, no. 2, pp. 343–362, 2003.

[12] a. Lindgren, a. Angelelli, P. a. Mendoza, and F. Chen, “Driver behaviour when using an integrated advisory warning display for advanced driver assistance systems,” *IET Intell. Transp. Syst.*, vol. 3, no. 4, p. 390, 2009.

[13] a. Lindgren, a. Angelelli, P. a. A. Mendoza, and F. Chen, “Driver behaviour when using an integrated advisory warning display for advanced driver assistance systems,” *IET Intell. Transp. Syst.*, vol. 3, no. 4, p. 390, 2009.

[14] N. Stanton, R. Lew, N. Boyle, R. J. Hope, B. P. Dyre, and E. a. Bustamante, “An Implementation of a Graded Deceleration Display in Brake Light Warning Systems,” *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 55, no. 1, pp. 1573–1577, Sep. 2011.

[15] J. Fagerlönn, S. Lindberg, and A. Sirkka, "Graded auditory warnings during in-vehicle use: using sound to guide drivers without additional noise," *Proc. 4th Int. …*, no. c, pp. 85–90, 2012.

[16] F. Naujoks, H. Grattenthaler, and A. Neukum, "Effectiveness of advisory warnings based on cooperative perception," *10th ITS Eur. Congr. Helsinki, Finl.*

[17] F. Naujoks and A. Neukum, "Timing of in-vehicle advisory warnings based on cooperative perception," *hfes-europe.org*, vol. 4959, 2014.

[18] A. Lindgren, F. Chen, P. W. Jordan, and H. Zhang, "Requirements for the Design of Advanced Driver Assistance Systems - the differences between Swedish and Chinese drivers," *Int. J. Des.*, vol. 2, no. 2, pp. 41–54, 2008.

[19] P. Alvarado Mendoza, a. Angelelli, and a. Lindgren, "Ecological interface design inspired human machine interface for advanced driver assistance systems," *IET Intell. Transp. Syst.*, vol. 5, no. 1, p. 53, 2011.

[20] J. G. Hollands and C. D. Wickens, "Engineering psychology and human performance," *J. Surg. Oncol.*, 1999.

[21] M. R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 37, no. 1, pp. 32–64, Mar. 1995.

[22] K. Smith and P. a. Hancock, "Situation Awareness Is Adaptive, Externally Directed Consciousness," *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 37, no. 1, pp. 137–148, Mar. 1995.

[23] G. Bedny and D. Meister, "Theory of activity and situation awareness," *Int. J. Cogn. Ergon.*, 1999.

[24] G. Underwood, A. Ngai, and J. Underwood, "Driving experience and situation awareness in hazard detection," *Saf. Sci.*, vol. 56, pp. 29–35, Jul. 2013.

[25] S. J. Kass, K. S. Cole, and C. J. Stanny, "Effects of distraction and experience on situation awareness and simulated driving," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 10, no. 4, pp. 321–329, Jul. 2007.

[26] N. Schömig and B. Metz, "Three levels of situation awareness in driving with secondary tasks," *Saf. Sci.*, vol. 56, pp. 44–51, Jul. 2013.

[27] G. H. Walker, N. a. Stanton, and I. Chowdhury, "Self Explaining Roads and situation awareness," *Saf. Sci.*, vol. 56, pp. 18–28, Jul. 2013.

[28] M. Cohen, O. Noel, and N. Fernando, "Spatial Sound for Vehicular Way-Finding and Situation Awareness," 2006.

[29] M. Howard, R. Sundareswara, M. Daily, R. Bhattacharyya, S. Kaplan, N. Mundhenk, C. Lee, and H. Neely, "Using tactile displays to maintain situational awareness during driving," *2013 IEEE Int. Multi-Disciplinary Conf. Cogn. Methods Situat. Aware. Decis. Support*, pp. 228–237, Feb. 2013.

[30] P. Salmon, N. Stanton, G. Walker, and D. Green, "Situation awareness measurement: a review of applicability for C4i environments.," *Appl. Ergon.*, vol. 37, no. 2, pp. 225–38, Mar. 2006.

[31] M. ENDSLEY, "Situation Awareness Global Assessment Technique (SAGAT)," in *Aerospace and Electronics Conference, 1988. NAECON 1988., Proceedings of the IEEE 1988 National. IEEE, 1988.*, 1988.

[32] MLA and R. M. Taylor, "'Situational Awareness Rating Technique(SART): The development of a tool for aircrew systems design.,'" in *AGARD, Situational Awareness in Aerospace Operations 17 p(SEE N 90-28972 23-53) (1990).*

[33] P. M. Salmon, N. a. Stanton, and K. L. Young, "Situation awareness on the road: review, theoretical and methodological issues, and future directions," *Theor. Issues Ergon. Sci.*, vol. 13, no. 4, pp. 472–492, Jul. 2012.

[34] C. D. Wickens and Y. Liu, "Codes and modalities in multiple resources: a success and a qualification.," *Hum. Factors*, vol. 30, no. 5, pp. 599–616, 1988.

[35] J. Rasmussen, "Models of Mental Strategies in Process Plant Diagnosis," in *Human detection and diagnosis of system failures*, vol. 14, no. 2, 1983, p. 145.

[36] H. T. Zwahlen, C. C. Adams, and D. P. DeBals, "Safety aspects of CRT touch panel controls in automobiles," in *Vision in Vehicles II. Second International Conference on Vision in Vehicles*, 1988.

[37] C. D. Wickens and J. G. Hollands, *Engineering Psychology and Human Performance*, 3rd editio. New Jersey: Prentice-Hall Inc., 1999.

[38] Y.-C. Liu, "Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveller information systems.," *Ergonomics*, vol. 44, no. 4, pp. 425–442, 2001.

[39] Y.-C. Liu and J.-W. Jhuang, "Effects of in-vehicle warning information displays with or without spatial compatibility on driving behaviors and response performance.," *Appl. Ergon.*, pp. 1–8, Nov. 2011.

[40] J. Fagerlönn, "Designing auditory warning signals to improve the safety of commercial vehicles," *Innovation*, 2011.

[41] O. Carlander, L. Eriksson, and M. Kindström, "Horizontal localisation accuracy with COTS and professional 3D audio display technologies," in *Proceedings of the International Ergonomics Association 2006 conference*, 2006.

[42] J. A. Veltman, A. B. Oving, and A. W. Bronkhorst, "3-D Audio in the Fighter Cockpit Improves Task Performance," *Int. J. Aviat. Psychol.*, vol. 14, no. 3, pp. 239–256, 2004.

[43] D. McKeown, S. Isherwood, and G. Conway, "Auditory Displays as Occasion Setters," *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 52, no. 1, pp. 54–62, Jun. 2010.

[44] C. Ho, C. Spence, and R. Gray, "Looming auditory and vibrotactile collision warnings for safe driving," in *PROCEEDINGS of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, 2013, pp. 551–557.

[45] B. K. Shaw, R. S. McGowan, and M. T. Turvey, "An Acoustic Variable Specifying Time-to-Contact," *Ecol. Psychol.*, vol. 3, no. 3, pp. 253–261, Sep. 1991.

[46] F. Leo, V. Romei, E. Freeman, E. Ladavas, and J. Driver, "Looming sounds enhance orientation sensitivity for visual stimuli on the same side as such sounds.," *Exp. brain Res.*, vol. 213, no. 2–3, pp. 193–201, Sep. 2011.

[47] R. Gray, "Looming Auditory Collision Warnings for Driving," *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 53, no. 1, pp. 63–74, Feb. 2011.

[48] B. Berglund, K. Harder, and A. Preis, “Annoyance perception of sound and information extraction.,” *J. Acoust. Soc. Am.*, vol. 95, no. 3, pp. 1501–1509, 1994.

[49] E. E. Wiese and J. D. Lee, “Auditory alerts for in-vehicle information systems: the effects of temporal conflict and sound parameters on driver attitudes and performance.,” 2004.

[50] P. Griffiths and R. Brent Gillespie, “Shared control between human and machine: Haptic display of automation during manual control of vehicle heading,” in *Proceedings of the 12th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, 2004.

[51] K. Suzuki and H. Jansson, “An analysis of driver’s steering behaviour during auditory or haptic warnings for the designing of lane departure warning system,” *JSAE Rev.*, vol. 24, pp. 65–70, 2003.

[52] Neil R. Carlson, *Physiology of behaviour*, 7th Editio. Massachusetts: Needham heights, 2001.

[53] J. B. F. van Erp, “Tactile displays for navigation and orientation : perception and behaviour,” Utrecht University, 2007.

[54] A. Adas, “the functionality of their ADAS systems.”

[55] The Swedish Transport Administration, “Analysis of Road Safety Trends 2011,” 2012.

[56] M. Belin, P. Tillgren, and E. Vedung, “Vision Zero – a road safety policy innovation,” *Int. J. Inj. Contr. Saf. Promot.*, vol. 19.2, pp. 171–179, 2012.

[57] National Bureau of Statistics of China, “Statistical Communiqué of the People ’ s Republic of China on the 2012 National Economic and Social Development,” 2013.

[58] F. Chen, M. Wang, X. Chan, and J. Li, “How Shall We Design the Future Vehicle for Chinese Market,” *Work A J. Prev. Assess. Rehabil.*, vol. 41, pp. 4265–4272, 2012.

[59] S. Ma, Q. Li, M. Zhou, L. Duan, and D. Bishai, “Road traffic injury in China: a review of national data sources.,” *Traffic Inj. Prev.*, vol. 13 Suppl 1, no. June 2012, pp. 57–63, Jan. 2012.

[60] W. Zhang, Y.-H. Huang, M. Roetting, Y. Wang, and H. Wei, “Driver’s views and behaviors about safety in China--what do they NOT know about driving?,” *Accid. Anal. Prev.*, vol. 38, no. 1, pp. 22–7, Jan. 2006.

[61] C. Xie and D. Parker, “A social psychological approach to driving violations in two Chinese cities,” *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 5, no. 4, pp. 293–308, 2002.

[62] J. Gong, A. Wang, Y. Zhai, G. Xiong, P. Zhou, and H. Chen, “High Speed Lane Recognition under Complex Road Conditions,” in *IEEE Intelligent Vehicles Symposium*, 2008, pp. 566–570.

[63] H. Zhao, M. Chiba, R. Shibasaki, K. Katabira, J. Cui, and H. Zha, “Driving Safety and Traffic Data Collection - A Laser Scanner Based Approach,” in *the IEEE Intelligent Vehicles Symposium*, 2008, pp. 329–336.

[64] X. Wu, Y. Peng, D. Ding, H. Liu, K. He, and F. Sun, “Color Vision-based Multi-Level Analysis and Fusion for Road Area Detection,” in *Intelligent Vehicles Symposium, 2008 IEEE*, 2008, pp. 602–607.

[65] B. Shneiderman and C. Plaisant, *Designing the User Interface*, vol. 2, no. 2. USA: Addison-Wesley, 2005.

[66] V. Neale, T. Dingus, and S. Klauer, “An overview of the 100-car naturalistic study and findings,” *Natl. Highw. Traffic Saf. Adm. Pap. (05-0400).*, pp. 1–10, 2005.

[67] M. Benmimoun and M. Aust, “Safety Analysis Method for Assessing the Impacts of Advanced Driver Assistance Systems within the European Large Scale Field Test euroFOT,” *22nd Enhanc. Saf. Veh. Conf. Washington, DC/USA.*, 2011.

[68] P. Lloyd, “Storytelling and the development of discourse in the engineering design process,” *Des. Stud.*, vol. 21, no. 4, pp. 357–373, Jul. 2000.

[69] and D. M. Langford, Joe, *Focus groups: supporting effective product development*. CRC press.

[70] T. Ranney, “Good driving skills: implications for assessment and training,” *Work A J. Prev. Assess. …*, vol. 8, pp. 253–259, 1997.

[71] J. Fagerlönn and H. Alm, “Auditory signs to support traffic awareness,” *IET Intell. Transp. Syst.*, vol. 4, no. 4, p. 262, 2010.

[72] M. Plavšić, G. Klinker, and H. Bubb, “Situation awareness assessment in critical driving situations at intersections by task and human error analysis,” *Hum. Factors Ergon. Manuf. Serv. Ind.*, vol. 20–3, pp. 177–191, 2010.

[73] J. Lee, J. Hoffman, and H. Elizabeth, “Collision warning design to mitigate driver distraction,” *SIGCHI Conf. Hum.*, vol. 6, no. 1, pp. 65–72, 2004.