Thesis for the Degree of Doctor of Philosophy in Human Technology Design

Same, Same but Different

On the Design of Cross-Regional Advisory Traffic Information Systems

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Gothenburg, Sweden 2017

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ABSTRACT

As the automotive markets increase rapidly in developing countries, the study of cross-regional differences is certainly becoming an important consideration for in-vehicle technology design. Particularly, when moving from immediate/operational responses to warnings towards tactical responses to advisory information, culture in the form of traffic safety culture (TSC) comes into play in relation to both the information needs and drive behaviours. This thesis explores cross-regional design of Advisory Traffic Information Systems (ATIS) – systems which provide feedforward information to support drivers' situation awareness and decision making during manoeuvres.

To gain knowledge of cross-regional design of ATIS, nine studies were carried out to study the regional differences between China and Sweden, looking into information requirements (via user studies) and drivers' response behavior when utilizing ATIS (via driving simulator studies). The research followed a human centered design process that involved drivers at the center of the process to understand their requirements, identify design ideas and evaluate the drivers' performance when using an adapted ATIS. In addition, naturalistic driving videos were adopted throughout the whole design process to address the contextual constraints.

Regional differences were found to significantly affect drivers' information requirements and behaviour patterns when using ATIS in driving simulations. Despite sharing the common information requirements in simple traffic situations, the cross-regional differences were significant in complex traffic scenarios with multiple road users. Furthermore, providing an ATIS adapted to the two TSCs, helped in improving drive performance, but did not change or shape the drivers' original behavior rooted in their own TSC.

To summarize: when the level of traffic complexity and information presentation timing increases, the diversity of drivers' information requirements and response patterns increases as well. Moreover, drivers from different TSCs might still "game" the system. This implies that ATIS designers need to study and understand drivers' motives of these utilizations, in order to refine the ATIS further and anticipate the alternative (mis)uses in respect to a given TSC.

Keywords: advisory traffic information system, cross-regional adaptation design, traffic safety culture, visual & auditory, user interface design, information requirements, driving behavior

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APPENDED PAPERS & DISTRIBUTION OF WORK

Paper A

Minjuan Wang, Sus Lundgren Lyckvi, and Fang Chen. 2016. Same, Same but Different: How Design Requirements for an Auditory Advisory Traffic Information System Differ Between Sweden and China. 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. ACM press.

Wang planned the study, conducted the focus group sessions, analysed the data and wrote the paper, supported by the two co-authors.

Paper B

Minjuan Wang, Sus Lundgren Lyckvi, Chenhui Hong, Palle Dahlstedt, Fang Chen. 2017. Using Advisory 3D Sound Cues to Improve Drivers' Performance and Situation Awareness. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM press.

Wang planned, conducted the study and analysed the data with the third author. The fourth author contributed significantly to the auditory system design and implementation. Wang wrote the paper together with the second author and support from the other authors.

Paper C

Minjuan Wang, Lian Duan, Jia Xin Wang, Lin Li, Dong Sun, and Fang Chen. 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.

Wang supervised the user interface design, experimental design, and duplicated the study in China, analyzed the data and wrote the paper with the help of the other authors.

Paper D

Minjuan Wang, Sus Lundgren Lyckvi, and Fang Chen. 2016. Why and How Traffic Safety Cultures Matter when Designing Advisory Traffic Information Systems. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM press.

Wang supervised the study, analysed the data herself, and wrote the paper with the other authors.

Paper E

Yuan Liao, Lian Duan, Minjuan Wang, Fang Chen. (In press). Cross-regional Study on Driver Response Behaviour Patterns and System Acceptance with Triggered Forward Collision Warning, 2017 IEEE Intelligent Vehicles Symposium

Wang worked together with the other authors on the study planning, experimental design, data collection and paper writing.

ADDITIONAL PUBLICATIONS

1. **Minjuan Wang,** Yi Ci Li, and Fang Chen. 2012. How can we design 3D auditory interfaces which enhance traffic safety for Chinese drivers? Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, ACM Press, 77–83.

2. David Marshall and **Minjuan Wang**. 2012. Development of an In-Vehicle User Interface for Traffic Information Presentation. Proceedings of the 44th Annual International Nordic Ergonomics and Human Factors Society Conference, Saltsjöbaden, Sweden.

3. **Minjuan Wang**, Dong Sun, and Fang Chen. 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.

4. Fang Chen, **Minjuan Wang**, Xi Chan, and Jiaqi Li. 2012. How Shall We Design the Future Vehicle for Chinese Market. Work: A Journal of Prevention, Assessment and Rehabilitation 41: 4265–4272.

5. Fang Chen, Călin Giubega, Peter Chen, and **Minjuan Wang**. 2014. Designing an In-Vehicle Advisory System to Support Traffic Awareness. 10th ITS European Congress, Helsinki, Finland, 10th ITS European Congress, 1–12.

6. **Minjuan Wang**. 2014. Designing Future Advisory Traffic Information Systems. Chalmers University of Technology. Thesis for the degree of licentiate of engineering.

7. Fang Chen, **Minjuan Wang**, and Lian Duan. 2014. Letting drivers know what is going on in traffic. In Advances in Intelligent Vehicles. Elsevier, 291–318. http://doi.org/10.1016/B978-0-12-397199-9.00010-07.

8. **Minjuan Wang**, Wei Lu, and Fang Chen. 2009. Designing a Multi-Modal In-Vehicle Internet-Based Information System for Good User Experience and Safe Driving. The 17th World Congress on Ergonomics 2009, Beijing, China.

ACRONYMS

AD	Automated Driving Technology
ADAS	Advanced Driver Assistance Systems
ATIS	Advisory Traffic Information Systems
3DAATIS	3D Auditory Advisory Traffic Information System
CP	Collision parameter analysis
FCW	Forward Collision Warnings
GOTA	Goal Orientated Task Analysis
HCD	Human Centered Design
HCI	Human Computer Interaction
HMI	Human Machine Interface
IVIS	In-Vehicle Information Systems
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
TSC	Traffic Safety Culture

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1 INTRODUCTION

With the development of automated driving technology (AD) and in particular advanced driver assistance systems (ADAS), human machine interface (HMI) design for in-vehicle information system (IVIS) has become different from what it is used be in earlier decades (Bengler et al. 2014). From a design point of view, the early ADAS mainly focuses on the function of warning, which means presenting only the most critical information in a clear way to support rapid decision making on an operational level. On this level, people will respond in a similar way, since these situations boil down to immediate responses to a crisis, as well as the inherent cognitive functions of the human brain. Nowadays, some automated driving functions for low speed and highway scenarios such as Tesla's Autopilot and Volvo's Pilot Assist, have already been introduced into current automotive markets. In the future, drivers may not need to monitor the car's activities and surrounding traffic situations, but have freedom to perform various secondary tasks.

As a consequence of AD development, the main function of ADAS is gradually shifting from warning drivers towards supporting them with situational information. In this thesis, we call this particular form of ADAS **Advisory Traffic Information Systems (ATIS),** which supports decision making on a longer time scale, i.e. on the tactical level, as compared to on the operational level. With ATIS, drivers can be provided with feedforward information, and thus have better situation awareness and decision making during manoeuvres. In this phase, regional differences in terms of drivers' historical driving experience, the complexity of their everyday traffic situations will affect the information needed to be presented and user interface design preference.

The automotive market is becoming increasingly globalized and is expanding rapidly from mature markets like Sweden into new markets such as China. Most current ADAS HMI design mainly focuses on the needs and preferences of drivers from Western countries and assumes a one-size-fits-all model (Khan & Williams 2014). ADAS has been developed well in areas where the infrastructures are well designed and road users generally follow the traffic regulations, for instance, in Sweden. However, driving conditions and related driver behaviour in countries like China are different in many dimensions (Blower & Woodrooffe 2012; Li et al. 2015). Compared to western cultures, China has a richer set of objects to be detected (e.g., pedestrians and electric bicycles), higher traffic density and more chaotic environment with unpredictable and more aggressive road users, all of which formulate a different culture of driving safety (Deng et al. 2013).

Differences in traffic situations, traffic infrastructure designs and driving behaviours lead to vast differences in how drivers perceive in-vehicle system interfaces and how drivers interact with them, even if they find them useful (Aaron 2003; Sears & Jacko 2009). The degree to which a product meets the preferences and expectations of users in a particular region or culture is critical to the success of the product in that area. Indeed, not taking regional differences into account when designing a system will not only result in low user acceptance, but may also be potentially dangerous (Nielsen 1994). Given the new sensor technology availabilities in the car, in theory, we can obtain much more information on current road and traffic situations. Therefore, one salient issue is to decide how much information should be shown in an advisory system, and when and how. This raises questions regarding what drivers need to know, what they want to know (which is not necessarily the same thing) and how to balance this in design without creating a cognitive overload. Moreover, we also need to consider cultural differences – in the sense of driving safety culture mostly. Is it possible to design a traffic advisory information system that fits all drivers (as per based on inherent cognitive abilities and general needs?) or should we design an interface that can be adapted towards the local driving culture? Lastly, we have to address the issues of driving safety and issues entailed by safe driving. It is risky to assume what driving safely means for all drivers and in all regions.

The aim of this research is to gain knowledge of designing cross-regional ATIS and exploring the cross-regional difference in design requirement and driver response behaviours between Sweden and China. We obtain design implications regarding how to accommodate the two different traffic safety cultures in one design and recommendations on ATIS design to better support driving safety.

1.1 Research questions

To reach the aim as mentioned above, two research questions were studied in the research.

Question 1: Do cross-regional differences influence drivers' information requirements in regards to the design of Advisory Traffic Information Systems, and if so, in which way?

Question 2: How does an ATIS, specifically adapted for cross-regional use, affect the driving behaviours of drivers from two target regions respectively?

1.2 Research scope

The scope of the research is to study cross-regional drivers' information requirements and user interface design to enhance driving safety by using ATIS, and furthermore, to evaluate the effectiveness of the ATIS via its user acceptance and impact on driving performance. Two findings are presented in this thesis:

1) Design insights regarding cross regional-adaptation design in terms of recommendation of methods and traffic scenarios, and design reflections collected from comparison studies.

2) Design implications about visual and auditory modality on ATIS design in terms of design suggestions gathered from studies on user requirement and simulator evaluation.

The research is conducted on the basis of three issues. First, according to the pre-defined research projects, ATIS design only focuses on **presenting situational information**

regarding different road users in relation to the driver. Infrastructures, landmarks, traffic signs, and the capabilities of sensor technology are not discussed.

Second, the ATIS focuses on presenting road user information that support the drivers **with operational and tactical levels of driving task during normal driving,** for instance, maintaining a proper distance, overtaking and lane keeping. Supporting a driver with trip planning from a strategic level (e.g. navigational tasks) is not considered in the design.

Third, **visual modality** and **3D sound** are the targeted information modalities which have been pre-defined by the research project**.**

To study the cross-regional difference, comparison studies were carried out between **Sweden and China**, and two low-fidelity driving simulators were built within the project in both countries. The lab environment of the driving simulators including layout, hardware and software settings, were identical between both countries. This allowed us to set up the same test environments for both countries, so that the results were comparable.

1.3 Research projects

During my PhD study, I was involved in two research projects funded by FFI-Vinnova, including EFESOS and ADAS Presentation Modalities. The studies and outcomes presented in this thesis are parts of the project deliverables.

The aim of EFESOS project (Environmental Friendly Efficient Enjoyable and Safety Optimized Systems) was to make future driving more environmentally friendly, enjoyable and safer by means of optimized systems. Within this research project, my task was to understand and collect drivers' information requirements on surrounding road users in various normal driving conditions, and to develop the design requirements and specifications into different concepts, in which surrounding road user information is presented to support driving safety and comfort. Furthermore, understanding regional differences between Swedish and Chinese drivers was part of the task as well.

In the ADAS Presentation Modalities project, the main aim was to further develop the design concepts generated from EFESOS, assess the effectiveness of the design, and identify the possible positive/negative adaptive behaviours of drivers.

2 BACKGROUND

2.1 Cross-regional design in automotive Human Machine Interface

There are different cultural-models that can be used to describe and understand the social behaviour and interactions of different cultures, For example, the Onion model suggested by (Trompenaars, Fons Hampden-Turner 1998). The model divided culture into three layers. The outer layer contains what people principally associate with culture. This explicit culture is represented by clothes, food, languages and etc. The middle layer of culture refers to the norms and values shared by a community, for instance, how one should behave in a culture, what is good and bad, as well as desirable and undesirable. The inner level comprises underlying and basic assumptions and expectation. Alternatively, Nancy and Hoft (1996) suggested the iceberg model, which provides a useful metaphor for describing the layers of culture and how aware we are of their influence on our lives. The model identifies three metaphorical layers of culture: layers of surface, unspoken rules and unconscious rules. Another concept of culture, not contradictory but rather refining the concept, is Hofstede's the cultural dimensions (Hofstede et al. 1997; Hoftede et al. 2010). Among these cultural models, Hofstede's cultural dimension theory is dominantly used in the domain of human computer interface (HCI) design. The model describes cultures from six dimensions, including power distance, individualism vs collectivism, masculinity vs femininity, uncertainty avoidance, long term orientation vs short term normative orientation, indulgence vs restraint. These cultural dimensions enable us to have general understandings of how and why orientations on various cultural dimensions may contribute to, or account for, differences in users' needs, preference and expectation of technology, and in artefacts across regional groups.

However, all these theories were not originally developed for the domain of vehicle HMI design. In-vehicle HMI design is substantially different from desktop or mobile applications. First of all, it's a safety critical domain. The design contextual constraints can range from the physical traffic environment to the intentions of other road users. In addition, it often happens that a driver needs to interact with multiple information sources simultaneously, e.g. other road users, traffic signs and information from in-car systems. Thus, design contextual constraints play a crucial role in in-vehicle HMI design.

For cross-regional culture concepts specifically in traffic safety, there is a concept called Traffic Safety Culture (TSC), which has been defined by (Edwards et al. 2014) as "the assembly of underlying assumptions, beliefs, values and attitudes shared by members of a community, which interact with a community's structures and systems (contextual factors) to influence road safety related behaviours". In this definition, **TSC is composed of common practices, expectations (motives), attitudes, and informal or hidden rules that drivers learn from society and traffic regulations and by observing others in**

their everyday driving situation (Lonero 2007)**. This in turn motivates and affects their risk perceptions, driving behaviours and strategies.**

Within cross-regional traffic safety filed, a number of researchers have studied differences in traffic incidents and fatalities among different national cultures. Lund and Rundmo investigated the differences in risk perception and attitudes towards traffic safety and risk between Norwegian and Ghanaian drivers, finding that the major difference between the two nations lay in risk perception (Lund & Rundmo 2009). By comparing drivers' self-assessed skills based on the accident data and fatality rates of six different European countries, Ozkan et al. concluded that cross-cultural differences mainly existed in driving skills and risk perception (Özkan et al. 2006).

Moreover, there are a few studies on regional difference that have been conducted to explore possible culture elements in the automotive HMI design. Khan & Williams (2014) carried out a study to identify the elements within infotainment HMI that are culturally specific in ease of use and acceptance, finding that there was a strong correlation between usability issues and regional differences. Heimgärtner et al. (2013) highlighted cultural differences in user preferences, system navigation and driving styles, which is conductive to cross-cultural in-vehicle information system design (Heimgärtner 2013; Heimgärtner et al. 2007). For example, they found that Chinese drivers preferred greater information density and faster information flow from navigation systems compared with German users. Young et al. (2012) conducted two studies to find regional differences in IVIS design needs and preferences across drivers from Australia and China. In their study, they used a questionnaire and interaction clinics to study the influence of cultural values and driving patterns on drivers' preferences, comprehension and interaction with IVIS interfaces. They found similarities and differences between Australia and Chinese groups in terms of preferences for IVIS input control types and labels and in the comprehension of IVIS functions. Specifically, Chinese drivers preferred symbols and Chinese characters over English words and had difficulty in comprehending English abbreviations. Gonçalves & Quaresma (2015) conducted an online survey and several focus group discussions to identify the different types of constraints affecting the relationship between Brazilian drivers and ADAS. The results revealed that the current ADAS design didn't consider the problems of the Brazilian traffic environment, the system couldn't support drivers' needs in their local traffic environments, resulting in low acceptance of local drivers. Unfortunately, the study did not clarify how to take traffic environment constraints into account during design. These findings from these studies underlined that the current trend of introducing Western-styled interfaces into other regions with little or no adaptation is unlikely to receive high acceptance from countries like China.

Sweden and China represent a Western matured automotive market and an Asian emerging market respectively. Lindgren et al. compared the preferences towards ADAS system between Swedish and Chinese drivers under common traffic scenarios (Lindgren et al. 2009). The results showed that generally they shared similar traffic regulations in the two countries, while the driving behaviours of both countries were highly culturally mediated as the Chinese drivers tended to drive more aggressively and obeyed the traffic rules less than Swedish drivers did.

In China, the automotive industry started booming in the 1990s and has been gaining momentum since. It's total number of motor vehicles increased from 1.59 million in 1978 to over 120.89 million by the end of 2012 (National Bureau of Statistics of China 2013). Now China has become one of the largest automotive markets in the world. From 2003 to 2012, the yearly increase of registered car numbers in China has been over 20%. This however also indicates that in China, the roads are getting crowded every year, and the distribution of drivers' population has shifted from professional drivers to first generation of drivers.

In addition, many drivers in China show less respect to traffic safety rules and regulations. As a result, there are many unexpected incidents in Chinese traffic situation (Zhang et al. 2006). A field observation study in Beijing reported that only 63.6 percent of the observed drivers used a safety belt, and just 40.4 percent signaled before changing lanes, and less than 1 percent turned on their headlights in light rain or moderate snow (Zhang et al. 2006). Among them, the underlying causing factors were excessive speed (14.0%), careless driving (12.5%), driving without a license (7.6%), driving in the wrong lane (5.2%), drunk driving (3.9%), other violations (21.3%), and other behaviors affecting safety (27.3%) (Zhang et al. 2013). Studies showed that the major factor contributing to the accidents was violations of traffic regulations due to lack of safety awareness (Xie & Parker 2002).

In comparison with China, Sweden benefits from over a 100 years of driving history, and is one of the safest countries regarding road transportation. In 2011, only 314 persons died and 4500 were severely injured (The Swedish Transport Administration 2012). Safety awareness among road users and transportation system design parties in Sweden is well established. For instance, "Vision Zero" which stands for no fatal traffic incidents for 2020 has been set as a national goal (Belin et al. 2012).

In short, even though Sweden and China have similar traffic regulations, the regional difference clearly shows in terms of traffic situation and road users' safety awareness. It can be summarized that Sweden and China are representative for two distinct TSCs.

2.1.1 Summary

Different models were developed to describe and understand the social behaviour and interaction between different cultures. As mentioned earlier in this section, the correlation between cultural difference and interface design has been extensively explored and studied in the traditional HCI domain; however, it's difficult to directly transfer this knowledge into the automotive HMI domain. Compared to HCI domain, automotive HMI is distinguished for the addition of driving tasks, dynamic traffic environment and multiple information sources, all of which may lead to different user tasks, needs and expectations.

As a result, differences in traffic situations, regulations, driving tasks and behaviours have a greater impact on what drivers need and what drivers accept, in certain automotive HMI designs.

To date, studies on the influence of cross-regional difference to ADAS design are few. Some key issues still remain to be solved. How does cross-regional difference interrelate with traffic situation, drivers' risk perceptions & behaviour? How do these interrelations result in a specific driver's acceptance and usability of a system?

Transferring automotive safety technology from one region to another can be problematic. As the automotive markets increase rapidly in developing countries, study of cross-regional difference is certainly becoming an important consideration for in-vehicle technology design, in order to achieve the best interaction between driver and system interface.

When comparing Sweden and China, studies showed that those two countries have similar traffic regulations, but the regional difference clearly identified in terms of traffic situation and road users' safety awareness. They represent two distinct TSCs. Therefore, in this research, Sweden and China were selected as two typical regional groups.

2.2 Driving and situation awareness

A large number of studies have demonstrated that **situation awareness (SA) is a fundamental contributing factor to decision making in a variety of complex domains**, including military (Endsley 2000), air traffic control (Keller et al. 2004) and automotive safety (Kass et al. 2007; Young et al. 2013; Underwood et al. 2013; Schömig & Metz 2013; Howard et al. 2013). Summala described a driver's ultimate goal as to drive without discomfort and stay within his or her comfort zone (Summala 2007). Hence, drivers are required to have a good SA in regards to the surrounding traffic environment, making it possible for them to foresee potential hazards in advance.

The essence of the concept of SA is about "knowing what is going on" (Endsley 1995). In the driving scenario, it's about knowing the vehicle's current position in relation to its destination, the relative positions and behaviour of other road users and potential hazards, and also be able to predict how these critical factors are likely to change in the near future. Good updating knowledge from moment to moment enables drivers' effective decisions in real-time driving situations. Among various SA definitions, three of them are dominated in the field of automotive safety.

- The three-level model introduced by Endsley (1995) describes SA as having three hierarchical levels (perception, comprehension and projection), that is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.

- The perceptual cycle model from Smith & Hancock (1995) presents that SA is maintained through the interaction between the person and use context. They view SA as generating purposeful behaviour (behaviour directed toward achieving a goal) in a specific task environment.
- The activity theory model by Bedny & Meister (1999) sees SA as an individual's conscious dynamic reflection on the orientation activities in the situations. It provides dynamic orientation to the situation, the opportunity to reflect not only the past, present and future, but the potential features of the situation. The dynamic reflection contains logical-conceptual, imaginative, conscious and unconscious components which enables individuals to develop mental models of external events.

Comparing the three SA theories, the perceptual cycle and activity theory models emphasize the impacts of the interactions between the individual and the world on the development and maintenance of SA. In contrast, Endsley's three-level model extracted the required SA from three different stages (perception, comprehension and projection) separately. This characteristic makes it appropriate and possible for eliciting accurate SA information requirements and measuring operators' SA level at each stage. Alongside Endsley's theory, she and others also developed a number of methods for SA design requirements and evaluations. For instance, goal orientated task analysis (GOTA)(Endsley 2016), situation awareness global assessment technique (SAGAT) (Endsley 1988) etc. Therefore, **the design principles in this research were inspired by Endsley's three level model.**

Taking a closer look at the three-level SA model, it follows the information processing model scheme along with the representation of the state of a dynamic environment, see Figure 2-1. SA connected the dynamic environment cues and operators' decision making. A study from Debra G. & Endsley (1996) found 88% of human errors were due to problems with situation awareness. The majority of cases where operators make bad decisions or execute their actions poorly is due to misunderstanding of the situation where they are in. Thus, the best way to support human performance is to better support the development of high levels of situation awareness. In a driving context, SA can be decomposed in the following levels.

- Level 1: Perception of elements in the current situation (selective attention and noticing). The driver perceives road conditions, traffic signs, and notices 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 (understanding or diagnosis of the 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 her/ his personal goal.

- Level 3: Projection of future status (anticipation). The driver forecasts the development of the hazards in relation to her/his vehicle and assesses whether the future trajectory will be under the allowable limits. This projection is the most critical elements in SA, it is simply a fact that corrective actions cannot be effectively achieved within a short time span before understanding the cause of the crisis. For example, it takes certain time to steer a vehicle away from a running pedestrian in a short distance at the intersection.

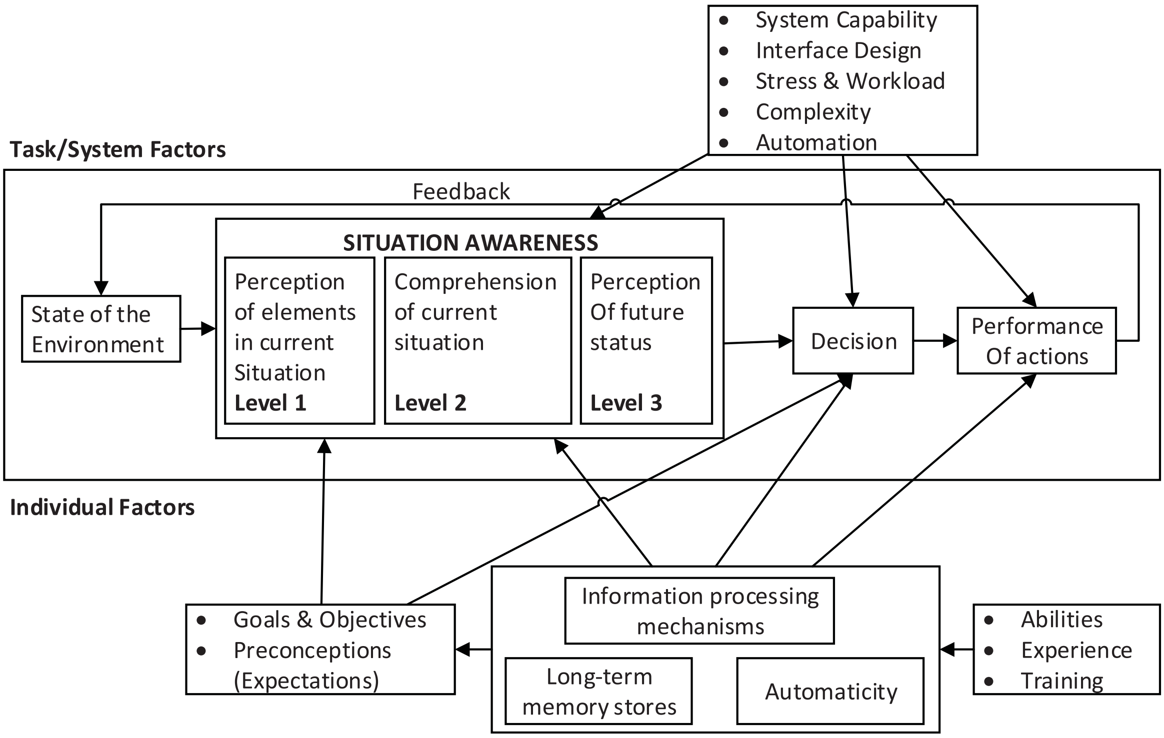


Figure 2-1 The three-level Situation Awareness model (Endsley 1995)

To design systems that provide a high level of situation awareness which support drivers with good projection of future status, the drivers' goal must be understood. According to Endsley's theory, SA is goal-oriented (Endsley 2016), which means the elements of the environment that people need to be aware of are determined based on the goals associated with that task. For instance, compared to a car following task, a lane change task requires SA information regarding both the front vehicle and the oncoming traffic. Therefore, it is essential to understand the drivers' goals and the information needs associated with their goals in different driving tasks.

2.2.1 DRIVING TASK IN RELATION TO SA LEVELS

Driving tasks are commonly categorized in terms of a three-level hierarchy, including operational, tactical, and strategic control (Michon 1985). Each level of control is related to a specific set of goals. The operational level corresponds to implementing vehicle control actions, such as speed control and steering control, to satisfy basic driving goals (e.g.

maintaining the speed limit and avoiding collisions). The tactical level corresponds to developing plans or reasons to realize near-term goals (e.g. manoeuvring, overtaking). The strategic level involves route planning under general constraints, such as a pre-defined arrival time, or optimization of route selection, like navigation, route planning, and risk evaluation, to satisfy global goals (i.e., arriving at a place within a certain time).

All SA levels are involved in different driving tasks. Both Matthews et al. (2001) and Ma & Kaber (2005) related three general types of driving tasks (operational, tactical and strategic) to the three levels of SA (perception, comprehension, and projection), the relationships are shown in figure 2-2.

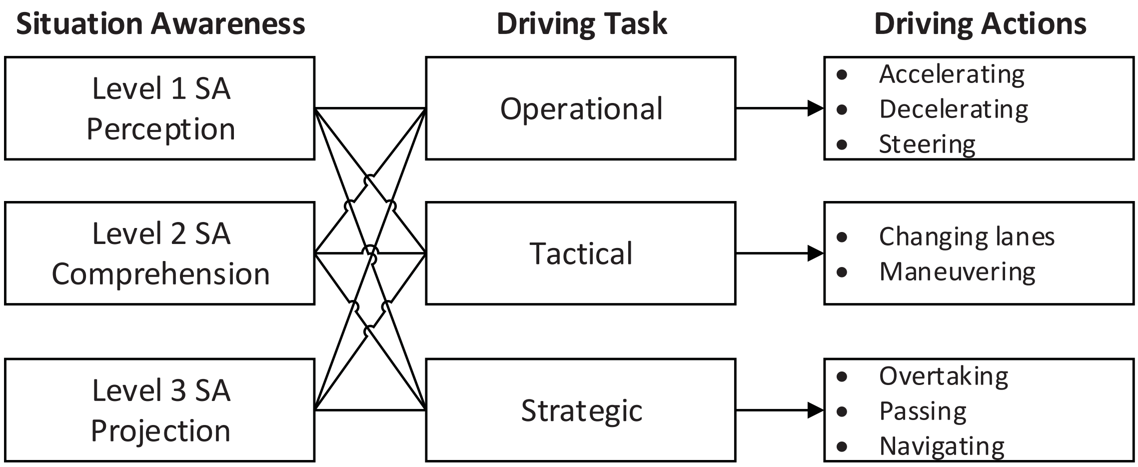


Figure 2-2 Relationships between situation awareness and driving tasks, adapted from Matthews et al. (2001) and Ma & Kaber (2005)

However, there are considerable differences in the SA levels of the different driving tasks, these differences potentially influence drivers' SA information requirements (Matthews et al. 2001), see in figure 2-3. At the operational level, drivers are engaged in actions upon vehicle dynamic control to maintain stable vehicle control. This type of task requires SA Level 1 on semi-automatic processes to ensure that the operations are performed appropriately. SA Level 2 and 3 may be involved. E.g., if the automatic processes "generate error messages".

At the tactical level, there is a high involvement of SA Level 1 and 2 in facilitating the local manoeuvring of the vehicle in traffic streams, in detecting appropriate environmental cues, and in comprehending the traffic scenario. Tactical tasks also require short span projection of driving environment, which is probably less than the extensive projection required for strategic driving tasks, e.g. navigational task. The focus at this level is on anticipating events especially those affecting safety and that might occur in near future. **In this research project, to enhance drivers' SA, ATIS design is focused on supporting driver's decision making on the tactical level by presenting the risk levels of surrounding road users' information.**

At the strategic level, SA Level 3 is highly required when navigational plans are formulated. At the time of execution, the strategic plan involves elements of SA Level 2, in terms of perceptual integration and comprehension. There is also a small contribution from SA Level 1 as the basis for the other two levels. The SA level 3 is particularly critical in future AD scenarios and transition period.

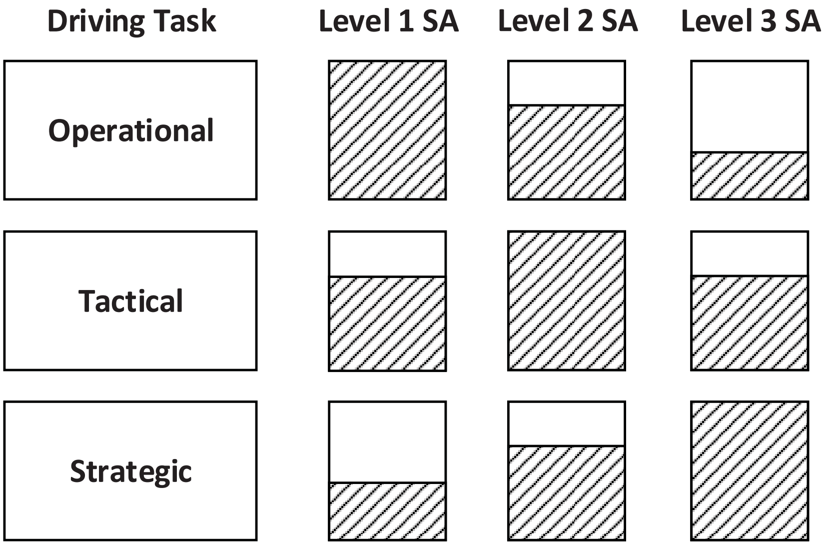


Figure 2-3 Degrees of involvement of levels situation awareness and drive tasks, adapted from Matthews et al. (2001)

2.2.2 SUMMARY

Situation awareness (SA) is a fundamental factor to decision making in a variety of complex domains. The essence of the SA concept is about "knowing what is going on". In the driving scenario, it's about knowing the vehicle's current position in relation to its destination, the relative positions, the behaviours of other road users and potential hazards, as well as about predicting how these critical factors are likely to change in the near future.

Endsley's three-level model extracts the required SA from three different stages (perception, comprehension and projection), respectively, which makes it appropriate and possible for eliciting accurate SA information requirements and measuring operators' SA levels at various stages. Based on this theory, many methods have been developed to quantify SA requirement (for example, goal orientated task analysis, GOTA) and to measure SA levels (for example, situation awareness global assessment technique SAGAT). In this study, the design principles were inspired by Endsley's three level model.

Since SA is goal-oriented, to design a system which can provide a high level of situation awareness, the drivers' goal must be understood (Endsley 2016). It is essential to understand information needs associated with drivers' goals in different driving tasks. Driving tasks are commonly categorized into three-level hierarchies, including operational control, tactical control and strategic control. Each level of control is related to a specific set of goals and involved with different level of SA. There are considerable differences in the SA levels among different driving tasks. These differences potentially influence drivers' information needs and should be applied to guide ATIS interface design.

2.3 Related work

As driving tasks 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 under critical situations (Wickens & Hollands 1999). To avoid such overload, there is a tendency to develop more pre-warning (advisory) visual information and use alternative modalities (e.g. auditory or haptic) to support drivers' attention and present driving-related information. In this research work, visual and auditory are target modalities according to the pre-defined research project. In the following section, the related research on ATIS design regarding these two modalities have been reviewed.

Regarding **visual modality** of pre-warning/advisory information, in a study conducted by Lindgren et al. (2009), an integrated advisory warning information display was compared with a display providing only critical warnings. The results showed that drivers kept a longer and thus safer distance to cars in front of them, when given advisory information rather than critical warnings only. In another study by Stanton et al. (2011), standard brake light displays were compared with a graded deceleration display expressing how hard the driver in front was braking. The results showed that the graded system produced more accurate behavioural responses during deceleration from the driver behind than the standard brake light display. Addressing warning timing issues, Naujoks and Neukum have carried out a series of studies that explored the effectiveness of advisory information in different timing scales and information specificity (Naujoks & Neukum 2014; Seeliger et al. 2014). The general findings underlined that early warning information has more positive effects on driver performance than late warnings when surprising situations occur. A more recent study from (Winkler et al. 2016) presents a driving simulator study of how drivers react upon a two warning stages system (warning and acute warning) in a head-up display. The system was tested in a collision avoidance scenario in urban areas. The results showed the drivers understood and reacted appropriately to the warning, as they braked less but in most cases sufficiently, in order to deescalate the situation and prevent an acute warning.

Regarding **auditory information**, recent researches show that auditory information can improve the safety of driving, shorten response time, and enhance accuracy and increase drivers' SA. For example, auditory looming warnings (i.e. sounds of which the intensity increases with the decrease of the distance between the driver's vehicle and the lead vehicle). Looming warning signals are informative to the driver because they take advantage of natural mapping. When a sound-emitting object is approaching an observer, the sound intensity will increase and the change rate of sound intensity will be accorded with the time to collision (TTC) and signaling urgency. Studies also show that auditory looming and its visual analogue can capture human attention by providing powerful signals to the human perceptual system (Leo et al. 2011). A comparative study was conducted by Gray, in which participants experienced four non-looming auditory warnings (constant intensity, pulsed intensity, ramped intensity, and car horn) and three looming auditory warnings (veridical signals, signals shorter than actual TTC time, signals longer than actual TTC time) under a non-warning condition. The results showed that looming sounds and car horn warnings had significantly faster brake reaction as compared with the other non-looming warnings (by 80 to 160 ms), moreover the number of false braking responses caused by car horn is much larger than that caused by looming sounds. Therefore, looming auditory warnings is an optimal choice both in response speed and accuracy (Gray 2011). At present, most research is mainly focused on rear end collision scenarios, while the mechanism of looming auditory cues under non-critical traffic scenarios is not clear.

Fagerlönn and Alm examined the role of auditory signs in supporting truck drivers' situation awareness. In this study, the participants were asked to memorize auditory signs and corresponding road users, after that their ability of correctly mapping auditory signs was tested, giving the sound as cue. Results showed that it took a longer time to learn arbitrary sounds and response performance by arbitrary sounds have a natural meaning in the driving context as compared with other sounds (Fagerlonn & Håkan 2010). However, in this study, participants were needed to recall the road users and situation, which is different from real traffic scenario. Therefore, it is necessary to explore how auditory signs actually work to support driver situation awareness for a real driving task.

Liu and Jhuang (Liu & Jhuang 2011) carried out a driving simulation study to evaluate the effects of five in-vehicle warning information displays upon drivers' emergent response and decision performance. The 5 displays included 1 visual display, two auditory displays with static and spatialized sound respectively, and two audiovisual displays with static and spatialized sound respectively. The results showed that a spatialized auditory display significantly improved drivers' decision performance in attention-dividing task. Similarly, Baillie et al. conducted a driving simulation study in which five auditory feedback methods were compared under autonomous and manual driving scenarios. The results showed that the spatialized auditory presentation method was superior to other methods, moreover drivers felt significantly safer in the presence of sound than in the absence of sound (Beattie et al. 2014). As shown by previous studies, the key issue was to evaluate drivers' response to displays. Yet, using the information for decision making when interacting with different road users remains unsolved.

2.3.1 Summary

To sum up, the previous research indicates that the concept of providing early information or advisory information (as opposed to warnings only) is a promising approach to increase driving safety and comfort. However, most of the studies are focused on the design of the signals per se, alarm timing, perception of the information signals, and tested traffic scenarios in previous works only involve single road users, for instance, car following scenario. Furthermore, studies of designing for cross-regional adaptive systems are scarce.

Therefore, the problem of how to design an advisory traffic information system to support driver's situation awareness in more real and complex traffic situation as remains in following aspects. 1) for different regions, 2) during real driving tasks, 3) focusing on early stages i.e., tactical level and 4) considering interaction with different road users, rather than just other vehicles.

3 RESEARCH APPROACH

This research is design-oriented research, which engages in understanding users' requirements, continuous iteration of ideating and critiquing the design solution to explore the design challenges, methods and process (Zimmerman et al. 2007). The outcomes of the research aimed to provide researchers and designers with inspiration and motivation for potential design solutions of cross-regional ATIS.

In this thesis work, a human centered design (HCD) process was brought into the design process (DIS & ISO 2009). It aims to understand what information drivers really need, rather than displaying information that is centered around technologies. As we know, with the advancement of technologies for sensors and vehicle to vehicle/infrastructure communication, enormous amounts of information can be made available to drivers. However, the ability of technology to provide data surpasses the human's ability to effectively process the information. This divergence creates a significant design challenge to the researchers and designers to balance between the data that is available and data that is needed, limited by the drivers' ability to receive and understand. Particularly, when taking cross-regional difference into account, drivers from different regions might have different goals and strategies when handling traffic situations. It further influences how the information should be prioritized, and what is the best way to present that information to accommodate their different goals and information requirements. **Thus, during the research process, drivers from both Sweden and China were involved in various user studies, in order to identify the design requirement gaps and how cross-regional factors would influence the use of ATIS.**

During driving, the drivers' decision making is highly dependent on the level of SA. Good SA secures efficient information processing, decision making and driving performance. Designing an interface that supports drivers' SA should not just simply provide information regarding the state of their environment. As discussed in pervious chapter, SA is goal orientated, the information that drivers want to receive is determined based on the goals associated with their current driving task. In this research, a driver's goal analysis was developed and applied guided by SA theory. It is used to determine what information drivers need to receive and understand relative to their goals, and what projections need to be made to reach those goals (see details in section 7.1). The method was inspired by a goal-directed task analysis methodology (Endsley 2016). These analyses provide the basis for understanding what information drivers need in order to fulfil their goals in their current driving tasks. **This thesis work applied SA concepts as design principles and applied related methods accordingly throughout the entire research work.**

Furthermore, **naturalistic driving videos were applied as design materials to address the contextual constraints.** ATIS design is significantly different from desktop and mobile application. Driving is dynamic and safety critical domain, drivers' goals are constantly changing according to the driving task and situation they involve. Moreover, drivers interact with the traffic environment, other surrounding road users and different systems in vehicle system simultaneously.

Naturalistic driving videos provided continuous views on how a driver behaves and interacts with a natural driving context (Guo et al. 2010), it recorded high resolution data for causations of crashes, near crashes, and incidents. Using the videos in user involved studies, for instance focus groups, it allows the participants have better and common understanding of the design context. By observing the videos in expert analysis, it allows for systematic analyses to the risk relations between the drivers and surrounding road users. The combination of user perspective and expert perspective using naturalistic driving videos provides comprehensive profiling of the most relevant information to support drivers at various traffic situations.

3.1 Method overview

This section summarizes the methods applied throughout the whole thesis work. The methods are grouped by each design stage and the overview of all methods are presented figure 3-1.

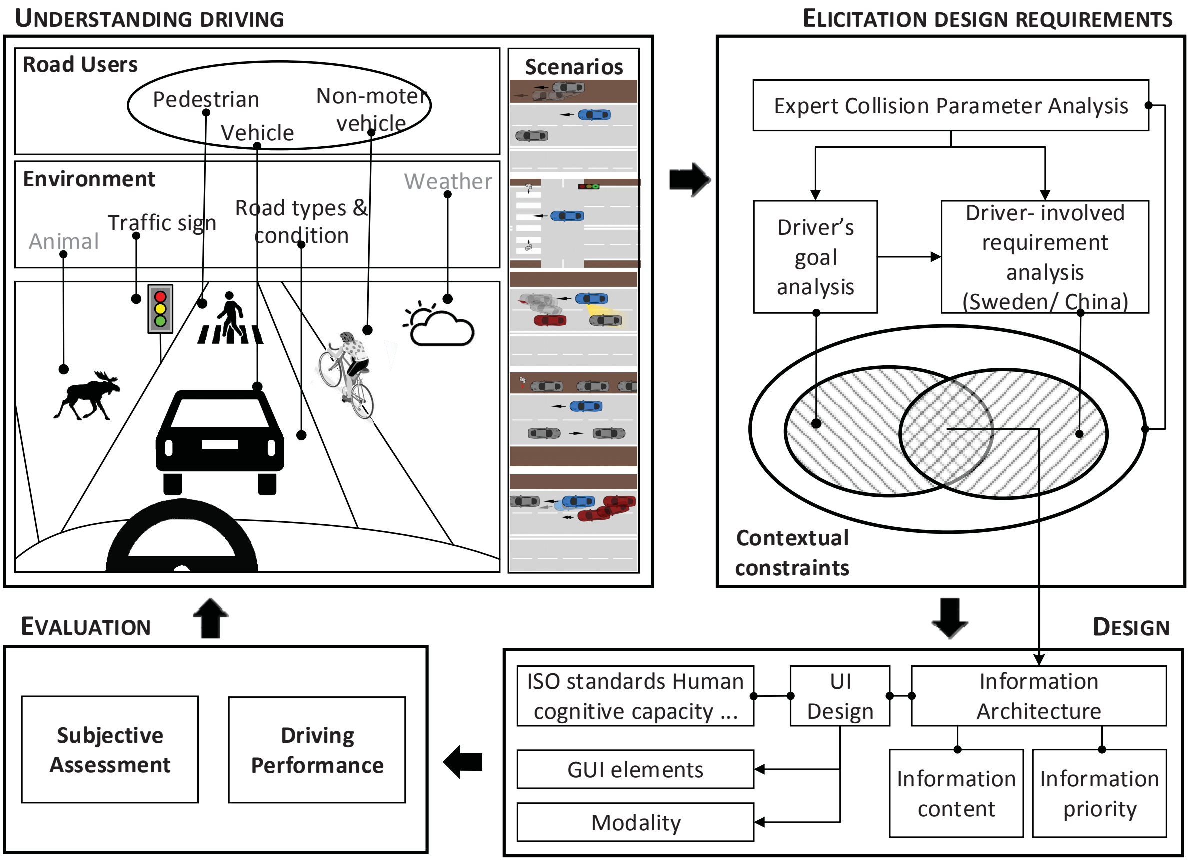


Figure 3-1 Overview of the research process

3.1.1 Understanding driving

At the beginning, over 100 hours of naturalistic driving videos were observed, and a number of traffic scenario videos were identified. They represent typical design scenarios for ATIS, the details can be found in (section 4.1 Pre-study observation & analysis of naturalistic driving videos). Those identified traffic scenarios were applied as design materials in terms of storyboard, design scenarios and test scenarios throughout the entire research.

A **literature review** study was also conducted to understand how the work integrates within the existing research field, and how it might advance the current state of the art (Zimmerman et al., 2007). At beginning of the research work, the related theories were reviewed and discussed in relation to the design of ATIS. The outcomes of the literature reviews set the stage for the upcoming design research and initiated several research questions and design ideas.

3.1.2 Elicitation design requirements

To understand the design requirements, two types of methods were applied: users involved analysis (focus group study) and expert evaluation (collision parameter analysis and drivers' goal analysis).

Focus groups are a form of group interview that capitalises on communication between research participants in order to generate data (Langford & McDonagh 2003). Details of focus group settings can be found in section 4.2. Naturalistic driving videos were used as dynamic storyboards for probing in the focus group study. It served as the basis for detailed analysis of traffic events and its interaction. It provided an opportunity that everyone in focus groups got the same view of the design challenges and context. In addition, the prototype was used to demonstrate the design ideas.

Collision parameter analysis (CP) is a method for analysing the driver's information requirements based on naturalistic driving videos observation. When observing the naturalistic driving video, the designers can consider what information is needed by a driver to understand and anticipate the current situation in naturalistic driving videos. CP analysis method was developed with inspiration from Time to Collison (Lee 1976). Since in our naturalistic driving videos, the data about drivers' actual speed, distance and trajectory is not included. Therefore, the CP analysis is a subjective assessment through observing the videos instead of real driving data. (Details can be found in section 4.5)

After gathering information requirements from CP analysis and focus group study, to further determined how to do information prioritization design. In this research, **drivers' goal analysis method was developed.** It was inspired by a goal directed task analysis (GDTA) by Endsley et al. (2003) and adapted for the use of naturalistic driving video analysis. This method is information requirements assessment technique, the general steps includes identifying the drivers' goals by observing how the driver operated the vehicle and estimated his/ her intended driving path from the naturalistic driving videos. Once understood drivers' intended goal, the intended goal break down into sub-goals. This method provides a systematic analysis of what types of information do drivers need to make better decision during this manoeuvre process. (Details can be found in section 4.5)

3.1.3 Design

Prototyping is the tangible creation of artefacts at various levels of resolution, for development and testing of ideas within design team and with clients and users(Hanington & Martin 2012). It helps designers to reflect on a design, illustrate their findings, or explore new alternatives (Benyon, 2010). Prototypes can be classified as hi-fidelity and lo-fidelity. Hi-fidelity prototypes integrate the design perspectives of information architecture and interaction. Lo-fidelity prototypes capture early conceptual ideas and normally in present with paper prototyping or wireframes. In this thesis work, different kinds of prototypes: paper prototypes, low and high-fidelity prototypes were used to evaluate the conceptual idea and identify usability issues iteratively.

3.1.4 Evaluation

There have been a number of definitions of usability evaluation. Nielsen defined usability as a quality attribute that assesses how easy user interfaces are to use (Nielsen 2009). He defined five measureable components of usability: learnability, efficiency, memorability, errors and satisfaction. Donald Norman's major focus of usability was on the user perspective, it shifts the emphasis of traditional definition from a product to the use (Norman 2004). Today, the most commonly cited definition of usability is probably the ISO 9241 standard, it defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 1998). This definition puts emphasis on the context of user. One of the most important contextual factors in defining usability for ATIS is that the driver's interaction with ATIS is not their main task, the primary task for the driver is driving safely and efficiently. This distinguishes ATIS usability from most other systems in terms of use context. Therefore, when testing ATIS, it is important to include the real driving contexts.

The methods of empirical usability evaluation mainly collect driving performance and behavior which can be conducted in the laboratory (**driving simulator**) environment or on real roads. In a laboratory, the driving environment is simulated. The range of driving simulator fidelity is various from single screen to moving base. Simulator-based studies are valuable for testing users in conditions which maybe not be safe or ethical in a real environment. In addition, it enables collection of a high volume of data in a relatively short time span.

In this research, a driving simulator was applied to evaluate how ATIS design influence drivers' performance and safety, the testing scenarios were programmed based on the identified traffic scenario from naturalistic driving video observations.

4 SUMMARY OF STUDIES

The nine studies were conducted within this research project, each study is presented with a summary of the aim, method and findings in this chapter. An overview of how each included study links to design process and included papers are presented in the figure 4-1.

	INCLUDED STUDIES	ROLE IN DESIGN PROCESS	PAPERS
AUDITORY	**STUDY I:** Naturalistic driving videos observation & analysis	Identified typical traffic scenarios	
AUDITORY	**STUDY II& III: Focus group studies between <u>Sweden & China</u>** Used naturalistic driving videos and predesigned 3DAATIS as instrumental tools to explore cross-regional **design requirements.** Conducted with 24 Swedish and 23 Chinese participants.	**Design Requirement Elicitation** Identified similar design preferences, i.e. sound design, information priorities under simple traffic scenarios; Diverse information preferences in complex traffic.	**Paper A** How Design Requirements for an Auditory Advisory Traffic Information System Differ Between Sweden and China
AUDITORY	**STUDY IV: Evaluation on 3DAATIS** Explored how drivers' **performance** and **situation awareness** were influenced by using a 3DAATIS in a driving simulator test, in this investigating the benefits and drawbacks that come with the use of ATIS. Tested with 30 participants in Sweden.	**Design & Evaluation** Proven benefits of using advisory, spatialized sound cues in vehicle traffic advisory information design & design implications.	**Paper B** Using Advisory 3D Sound Cues to Improve Drivers' Performance and Situation Awareness
VISUAL	**STUDY V & VI: Evaluation of ATIS 1st iteration between <u>Sweden & China</u>** Two GUIs of ATIS were tested, the first GUI only presents the **directional** information of road users (RU) around the car, while the second presented **direction** as well as the **types of RU**. Studied how an ATIS developed based on Swedish drivers' requirements inflenenced Chinese drivers' performance. Conducted with 20 Swedish and 24 Chinese participants	**Design & Evaluation** The GUI with both direction and the type of road users worked better with both countires in terms of reducing collision rates etc., Feedback regarding redesign of GUI were collected from both groups.	**Paper C** Drive Advisory System: Do Swedish and Chinese Drivers Appreciate It in the Same Way?
VISUAL	**STUDY VII &VIII: Evaluation of ATIS 2nd iteration in <u>Sweden & China</u>** The new version was tested to explore: whether it is possible to design an interface for drivers from more than one traffic safety culture, making them drive more safely? And will they respond in the same way to the information given by the ATIS? Tested with 22 Swedish and 24 Chinese participants.	**Design & Evaluation** The study showed distinct driving strategy patterns between Swedish and Chinese participants. In addition, it identified how two groups utlized ATIS in accordance to TSC	**Paper D** Why and How Traffic Safety Cultures Matter when Designing Advisory Traffic Information Systems
VISUAL & AUDITORY	**STUDY IX: Evaluation of Forward Collision Warning in <u>Sweden & China</u>** Studied drIvers' response behavior patterns towards two alarm timings, in car-following scenarios with different traffic density. Tested with 30 Swedish and 32 Chinese participants using a driving simulator.	**Evaluation** The results indicated that Chinese steer more frequently than Swedish drivers in response to triggered alarm, no matter alarm timing or traffic density, and preferred later alarm timing.	**Paper E** Cross-regional Study on Driver Response Behavior Patterns and System Acceptance with Triggered Forward Collision Warning

Figure 4-1 Overview of included studies and role in the design process

4.1 Study I Observation & analysis of naturalistic driving videos

Many naturalistic driving projects have been conducted, such as the 100-Car project (Naturalistic Driving study in United State)(Neale et al. 2005) and similar projects like Sweden-Michigan Naturalistic Field Operational Test (Victor et al. 2010) etc. The data from these projects provided a good understanding of accident causes and are invaluable for the ADAS evaluation. The naturalistic driving videos from those studies provide continuous views of what happens inside and outside the vehicle. It can provide a range of interesting and insightful information about how and why a driver interacts with the surrounding road users and in vehicle systems. However, the potential utilization of naturalistic driving videos from FOT studies in the early stage of ADAS HMI design has not been well explored.

The purpose of this study is to identify the typical traffic scenarios during normal driving, and form a traffic scenarios database which can be used to serve different design purposes in this research.

4.1.1 Method

In this study, over 100 hours of naturalistic driving videos from Sweden and China were first observed and classified according to variables of interests in relation to the research purpose. The extracted video clips contain the incidents requiring rapid response and rewound the videos 10s prior the incidents. After watching carefully, seventy (70) short video clips were extracted from the video records. These video clips were kept in a database where they were sorted into groups. The group is categorized to 14 different types. The database was categorized in a way, so that in future it would be easy to find the desired video clips quickly and efficiently.

The categories were, camera view, video length, vehicle type, pedestrian type, road type, overtake/overtaken and incident description. Some details categories are presented in Table 4-1 below.

4.1.2 Results

A database containing 70 traffic incidents videos was developed. This database provided a rich design materials, researchers or designers are able to see all the interactions between drivers and environment before a driver encounter to a hazard and analyse the events retrospectively. It provides enough details to analyse the traffic environment and drivers' interactions qualitatively.

There are 25 incidents that were developed into storyboards to address some of the typical traffic scenarios. Those storyboards were applied in the design stage and design of test scenarios in simulator evaluations. The examples of the storyboards are shown in Table 4-2, 3 and 4.

The limitations with these naturalistic driving videos were first, when observing the videos, it was difficult to catch drivers' motivation during the critical situation. Second, high cognitive workload for observation and classification was imposed.

Scheme Code	Definition
Vehicles	
Small	Three wheelers, scooter, motorcycle
Medium	Cars, Microbus, four-wheeler-SUV, small SUV's.
Heavy	Bus, Trucks.
Pedestrian	
Single	Only one pedestrian was presented in a single frame.
Multiple	Multiple pedestrians were seen in a single frame of the video clip.
Passing	Pedestrian were passing in the road, island.
Crossing	Pedestrian were crossing in front of the vehicle.
Bicycle	People are using bicycle.
Man	Men were visible.
Woman	Women were visible.
Senior	Senior citizens were visible.
Kid	Kids were visible
Overtake	
Overtake	The vehicle overtook some other vehicle.
Overtaken	The vehicle is overtaken by some other vehicle.

Table 4-1 Naturalistic driving video coding scheme

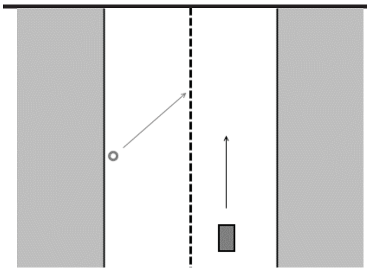
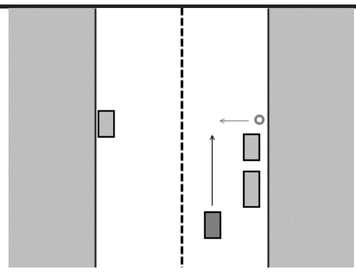
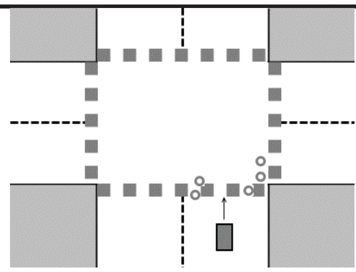
		
Ped cross road	Ped cross road from blindspots	Ped at intersection

Table 4-2 Samples of pedestrian scenarios

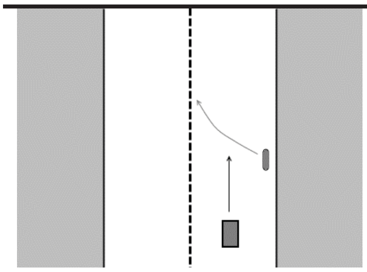
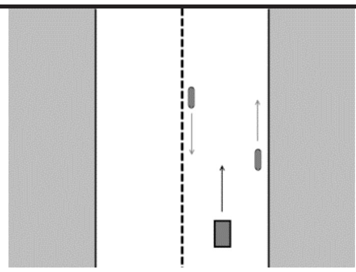
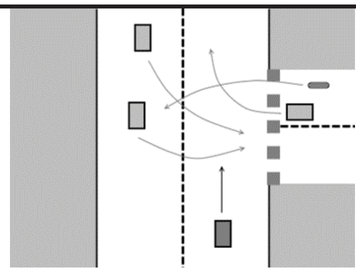
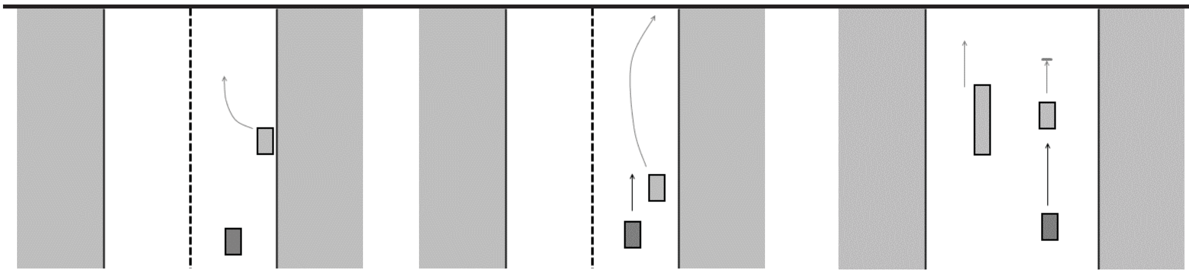
		
Biycle cross road	Bicycle bike along road	Biycle at intersection

Table 4-3 Samples of bicycle scenarios



Parking vehicle cut in	Front vehicle changelane	Lead vehicle decelerate

Table 4-4 Samples of vehicle scenarios

4.2 Study II & III Understanding & eliciting the design requirements in Sweden and China

Paper A: Same, Same but Different: How Design Requirements for an Auditory Advisory Traffic Information System Differ Between Sweden and China

Many advanced driving assistance systems have been developed based on the western automobile markets. However, it is widely known that the differences between Western and Asian markets are large in terms of traffic safety culture, traffic situation, and driver behaviour.

This study aimed to explore the differences between Swedish and Chinese drivers' information requirements in regards to a 3D Auditory Advisory Traffic Information System design (3DAATIS).

A focus group study has been conducted based on a 3D Auditory Advisory Traffic Information System (3DAATIS), in combination with selected traffic scenarios displayed as movies. Hereby we could study drivers' information requirements under different traffic scenarios and explore how regional factors like driving habits, behaviour and traffic situation may result in different design requirements.

4.2.1 Method

The study involved a total of 47 participants. In Sweden there were 24 (19 male and 5 female) making up 7 focus groups. In China there were 23 (16 male and 7 female), making up 6 groups. The focus group settings were intended to mimic a realistic driving context by providing the pre-programmed conceptual prototypes with four selected naturalistic driving videos. Each selected video contains several traffic incidents which depicted what we had found to be the most frequent and typical traffic situations when driving on city roads, on highways, on roundabouts and in residential areas. Moreover, they also involved different types of road users and levels of traffic density. The rich information from the videos provided a good starting point for focus group discussions. Each video was approximately 25 seconds long, and contained 3 or 4 interesting incidents, which were categorized as listed in Table 4-5.

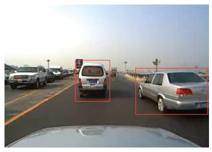
Scenario categories	Samples scenario
A: Interactions with a single road user Only one road user has potential conflicts with the driver	
B: Interactions with multiple road users More than one road user has potential conflicts with the driver	
C: Interactions with a single road user in special road situations Traffic regulations are unspecified, e.g., roundabout, intersection	
D: Interactions with multiple road users in special road situations Traffic regulations are unspecified, e.g., roundabout, intersection	

Table 4-5 The categories and samples of scenarios

The 3DAATIS prototype used a surround sound system to present traffic information in terms of road user types, location, movement, and distance in relation to participants' car (their sitting position). Auditory icons and synthesized sounds were selected as auditory information cues in this study.

The experiment included two sessions: first, the participants were introduced to the purpose and procedure of the study and received enough training to understand the design and functionality of the system, meanwhile, background information and sound samples matching test were collected. In the second part of the study, the four videos were played one by one together with auditory cues provided by the 3DAATIS prototype; once with auditory icons, once with synthesized sounds. The order was randomized for each focus group session. Participants were asked to observe the traffic events in the video and reflect on the design of the 3DAATIS. The discussion focused on three main topics:

- General opinions and attitude towards 3DAATIS
- Preference of sound designs
- Information requirements under different traffic scenarios and reflection on their own experience

The data analysis method utilized a combination of question-based structural code and thematic analysis (Braun & Clarke 2006). The data analysis was based on the notes taken during the focus group sessions and video transcripts of the discussions.

4.2.2 Findings

In general, the similarities between Swedish and Chinese focus groups are large in regular situations, for instance, scenario category A from Table 4-5, simple situations where drivers only interact with single road users.

1. **The concept of 3DAATIS was highly appreciated by both countries**. Both Swedish and Chinese participants expressed that situational auditory information could provide them with a good understanding of the traffic dynamics. Being aware 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 that dangerous situations can be prevented or at least anticipated.
2. **Drivers' information prioritization** results showed that even though both countries have different traffic scenarios and driving behaviour, **the information needs and prioritization during traffic scenarios category A (only interaction with one road user at the time) are similar.** Vulnerable road user information is perceived as higher information priority compared to motorized road users. Regarding information around the car, generally, blind spot information and urgent information in the front zone are appreciated. While driving, visual attention is still the primary information source channel, and auditory information is considered as supplementary information source channel to cover the disadvantage of visual channel. In regular situations, presenting non-critical information may increase annoyance.

However, **the differences between two countries was significant in traffic scenarios category B, C and D (interaction with multiple road users and under special road situations).**

1. **Swedish drivers require information from the front side which are relevant to the driving direction, while the Chinese driver often ask for information not only the front side, but also from rear and side areas.** It indicated that as drivers in Sweden respect and follow the traffic regulations well, they trust and rely on other drivers and also obey the rules. While in China, as in many industrial developing countries, with relatively high traffic density, people (not only the driver, but also many other types of road users) try to fill in all possible space in road, and such habits also create complex traffic scenarios.
2. The typical situations include **cut in, hard braking and entry ramps**. Chinese driver would often take the strategy of changing lanes, or just drive to the side to avoid the conflict. The differences in these scenarios implied how drivers expect the system to support them in driving from different regions.

The results of information requirements also underlined that identifying requirements different from different traffic scenarios will be a feasible approach to succeed in adaptation design. In order to make the design successful cross regionally, it is important **to actively involve the users from the target cultural populations** into the design process. Secondly, in this study, Swedish and Chinese participants have similar information requirements in less complex situations, for instance in regards to emergency and vulnerable road users. For this type of scenario, adaptation design can focus on **understanding the risk perceptions in order to adjust system parameters,** e.g. auto-braking distance. However, when the situations are complex, and multiple road users are involved, two groups expressed different strategies when handling the situation, as per the dependency on their respective Traffic Safety Cultures. In conclusion, adaptive design for complex traffic scenarios must look into **information requirements related to Traffic Safety Culture, and drivers' motives or intention under each scenario, the underlying reasoning of their behaviour patterns**.

4.3 Study VI Design & evaluation of 3D Auditory Advisory Traffic Information System

Paper B. Using Advisory 3D Sound Cues to Improve Drivers' Performance and Situation Awareness

Based on the results from Study I & II design requirement elicitation on 3DAATIS, a follow up expert focus group study with five design experts was carried out: one in-vehicle acoustic researcher, two acoustic designers from Swedish automotive OEMs and two in-vehicle interaction designers. The purpose was to narrow down the design requirements collected from Studies I &II. The framing was that it should be possible to use these recommendations for a sound system in vehicles being produced five years from when the workshop was held. The result from the workshop was a number of design decisions.

1. Auditory information should be presented on the critical level (warning sounds), and the safety level (advisory sounds which direct drivers attention to potential hazard).
2. Only one type of sound is to be used, since the intention of this system is to direct driver attention to potential hazards, which they can then confirm visually.
3. The sound is to convey urgency, direction and movement. Direction and movement go together quite naturally, since the sounds are displaying moving objects after all. The urgency parameter distinguishes whether a sound is advisory or warning.

The results from the expert focus group laid the foundation for the design of the system tested in this study.

The aim of this study is to understand **how can a 3D Auditory Advisory Information System influence driver's situational awareness and driving performance?**

Due to the limited project budget, the comparative study wasn't carried out in China. Therefore, in this study, we only investigated how Swedish participants utilized 3DAATIS under different traffic scenarios.

4.3.1 METHOD

This study was a driving simulator study with 30 Swedish participants. The study utilized a within-subject design, treatment conditions (without 3DAATIS / with 3DAATIS), and five traffic incident scenarios (see below figure 4-2) as independent variables.

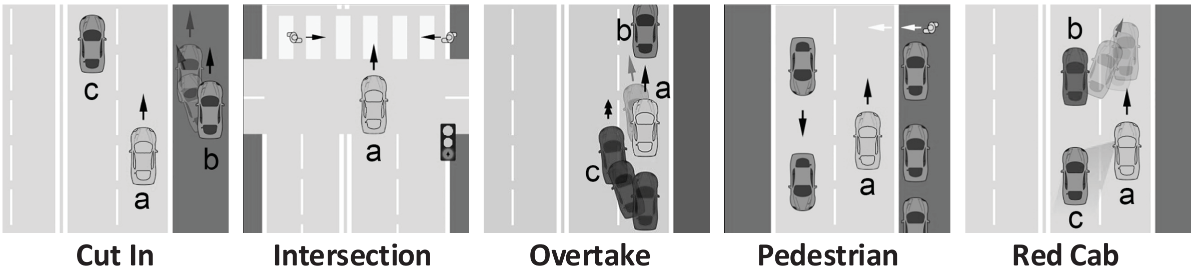


Figure 4-2 The traffic scenarios studied

A prototype of a 3DAATIS was developed to provide relevant advisory information regarding road users in the vicinity of their own vehicle. This information includes in which direction the road users move and what risk level they are at (in terms of time/ distance to collision). The aim of the 3DAATIS was that the participants should be able to identify the origin and moving location of the sound cue. Moreover, the participants should be able to **map an increasing risk level with changes in the sound.** There were two levels: **advisory and warning sounds**.

Participants' driving performance and situation awareness data were measured and collected. Finally, in a post-interview section, the participants' opinions on the system were obtained. The overview of the study is shown as below.

Sound Expert Work Shop	The design decisions: 1) 3DAATIS presents information on the critical & safety level; 2) only use earcons; 3) the sound cues convey other road users' urgency, direction and movement information
Sound Sample Design	An earcon was designed by a sound designer and tested iteratively within the research group. Overtones were added (to decrease the risk it would be masked by another sound).
3DAATIS Prototype	A 3DAATIS prototype was developed by using a combination of Pure Data and Matlab and projected them in a 5.1-channel surround sound system.
Experimental Design	1) Introduction: test purposes and questionnaire on hearing capabilities and driving experience; 2) Training: full understanding of the simulator and 3DAATIS functions; 3) Test: two trails (with/ without 3DAATIS) in 5 test traffic scenarios in randomized order. SA and drive performance data were measured; 4) Post interview: feedback on the system design.
Data Analysis	For driver performance data, a paired t-test was used, for the post-interviews thematic analysis method was applied.

Figure 4-3 The study procedure

4.3.2 Findings

In summary, **participants perceived the system as useful; response times got shorter, and in a majority of situations, SA and driving performance improved**. As for acceptance, the 3DAATIS received notable positive scores on perceived usefulness, which means that **participants are open for spatialized sound cues.** Moreover, we used only one sound displaying three dimensions (direction, movements and urgency), and participants did not have any problem understanding this underlying concept, meaning that it was **easy to learn**.

The most important finding is that **spatial sound cues work effectively in situations involving single road users in the front and side sectors**. In less complex situations, or when single road users occur in front or in the front side sectors, drivers can quickly perceive and associate the localized sound cues with what they see from the traffic scenario outside the car; feedback is instant. Therefore, even though sound localization resolution is quite low, drivers' performance and SA in these situations were still improved, as exemplified in the scenarios of Cut In, Intersection and Pedestrian.

The second was that **if the situation is complex, spatial sound cues can be confusing**. If, for instance, there are several road users around the car, and/or sound cues come from the back, the limited auditory localization resolution and/or front-back confusion makes the information ambiguous, confusing drivers. This was clearly shown in the scenarios of Red Cab and Overtake indicated by the number of collisions, response times and driving performance. In the Red Cab-scenario, neither the system nor the human capability to discern the exact direction of the sound could help the drivers to tell the two sound cues for two vehicles apart; the angle between them was too narrow. The possible design recommendation in these situations, where multiple sound cues are presented in the narrow dimension, **is that supporting sound cues with visual information to avoid confusion ought to be beneficial**.

Last, the results of this study also concluded that it **is beneficial to support drivers with both advisory/situational information sound cues and warning sounds.** The results from the situation awareness global assessment technique (SAGAT) enquiry showed increased understanding and projection of the future situation in three (Cut In, Pedestrian and Overtake) of the four scenarios measured in this study. In addition, drivers' response times improved in all scenarios as compared to baseline. These results suggest that drivers, whose attention has already been directed towards a potential hazardous situation, either avoid it all together, or react faster to the warning sound. It is worth noting especially, that in the Overtake-scenario, the overtaking car came up so fast, that the system went directly into warning-mode, skipping over the advisory level, which also indicates that the advisory level really adds to SA and performance. For Overtake, drivers did react faster, but not in an efficient way; the front-rear confusion from the sound display and short reaction time due to the only warning level, created panic and an inefficient cognition process for performing the right action.

In the study, we designed custom sounds devoid of the harsh and inharmonious qualities associated with warning sounds, which we assumed would work better for advisory purposes. Despite the fact that the sounds now were no longer typical, attention-grabbing, warning sounds, drivers still observed them and responded to them efficiently. Thus, one conclusion is that **non-obtrusive, harmonious sounds work well to present advisory driver information**.

4.4 Study V & VI First iteration: Design & evaluation of Advisory Traffic Information System in Sweden & China

Paper C: Drive Advisory System: Do Swedish and Chinese Drivers Appreciate It in the Same Way?

In this study, the first iteration of conceptual designs of visual ATIS was developed. The design requirements were collected from previous projects within the research group (Mendoza et al. 2011; Lindgren et al. 2008). For instance, providing continuous integrated information regarding surrounding environment instead of only presenting separated information from different ADAS; information should be presented not only on a warning level but also on an advisory level.

This study aimed to evaluate how the advisory traffic information systems developed in Sweden affect Swedish and Chinese drivers' behaviours respectively?

4.4.1 Method

In the conceptual design phrase, an iterative design process was used which included paper and digital prototyping. Usability tests were conducted with five HMI experts within traffic safety and in vehicle interaction design domains. Two conceptual designs of ATIS were developed: 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. In design 2, four types of road users (pedestrian, cyclist, motorcyclist, and vehicle) are included and if more than one road user is located in a region, a multiuser icon is used. The colours yellow, amber and red 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 (informative) to amber (advisory) and finally to red (warning). The threshold values for the TTC are nine, six and three seconds. Figure 4-4 shows examples of two designs.

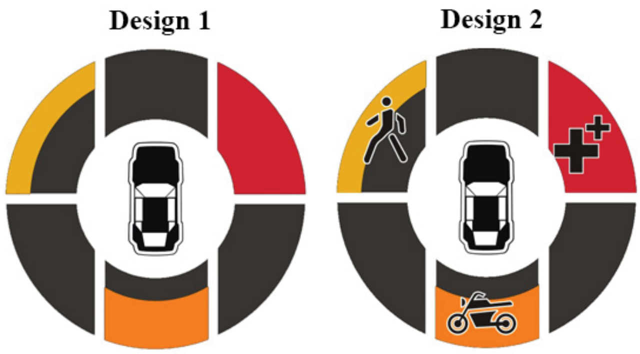


Figure 4-4 Two conceptual designs of visual ATIS

The experiment was carried out in both China and Sweden with 25 Chinese participants and 20 Swedish participants. At the beginning of experiment, two designs were introduced to the participants, a pre-questionnaire regarding participants' background information and their attitudes about the system before the test drive was collected. During the test, each participant drove three times in a randomized order: baseline without any display, once with Design 1 and once with Design 2. After driving with both Design 1 and Design 2, an acceptance questionnaire was sent out again to measure drivers' satisfaction and usefulness towards to the system. After all three test trials were completed, a post questionnaire were asked which design they preferred and why.

4.4.2 Findings

The results of the study showed that participants' acceptance towards both designs remained the same before and after using the system. However, Swedish participants perceived significantly higher usefulness and satisfaction levels than Chinese drivers in general. This finding was also proven by the followed-up interviews; Swedish participants appreciated the designs of icons, shapes, and colours. Since the prototypes were designed and developed together with Swedish users and earlier usability test were conducted in Sweden as well. The results underline that to succeed in a cross-regional localization design, it is vital to involve the target groups during the early design process.

The results of drivers' preferences on different information regions revealed Swedish participants were mostly interested in information from front areas (Front Right, Front Left and Back Centre) in both design 1 and design 2. In contrast, Chinese drivers required more information from the rear areas (Back Centre, Back right and Back Left regions) with Design 1. However, with Design 2 (with road users' information) Chinese participants slightly changed their information requirements from the rear to the front areas. The follow up interview results indicated that **Chinese participants found the additional pedestrian information was helpful**, as it could assist them to better predict and react appropriately to the incidents.

The **driving performance** data showed that when using **design 2** (with road users' information), participants **drove more safely** than design 1 in terms of number of collisions. However, when using designs 2, Chinese participants tended to utilize the road user's information to adjust their driving strategy accordingly.

In general, both groups preferred and performed better with the design 2 with road users' information, however, from the post questionnaire, they also commented that current design of both design were distracting in terms of colour use and amount of presented information.

4.5 Study VII & VIII Second iteration: Design & evaluation of Advisory Traffic Information System in Sweden & China

Paper D: Why and How Traffic Safety Cultures Matter when Designing Advisory Traffic Information Systems?

Based on the results from Study IV & V, a new iteration of ATIS was developed.

The aim of the study was to understand the possibility of designing an interface for drivers from more than one region, and how will they respond to different traffic scenarios and to the information given by the ATIS?

4.5.1 Method

This study was divided into three phases: 1) Through naturalistic driving videos analysis, the design requirements were generated 2) Based on the feedback of focus groups, the conceptual designs were iterative. 3) Design and evaluation in a driving simulator.

1) Naturalistic driving video analysis

- **Collision parameter analysis**

Collision Parameter analysis (CP) is a method for analysing the driver's information requirements based on naturalistic driving videos observation. The purpose is to deepen the understanding of the types of information that are important to a driver in a particular traffic scenario. When observing the naturalistic driving video, the designers can consider what information is needed by a driver to understand and anticipate the situation.

CP method was developed with inspiration from Time to Collison (Lee 1976). In our naturalistic driving videos, the data about drivers' actual speed, distance and trajectory is not included. So the CP analysis is a subjective assessment through observing the videos. Several parameters were used, including, trajectory, speed, location and distance of road users, acceleration, and steering of the cam-car driver. All of these parameters together could reflect the threat levels between the driver (cam-car) and other road users. A summary about how to analyse drivers' behavior are provide in Table 4-6.

Parameter	Description
Speed	Driver (cam-car)'s driving speed is defined as high, medium, or low according to the traffic environment.
Brake/ Acceleration	Does the driver (cam-car) brake or accelerate, suitable or not suitable at that moment.
Steering	Does the driver (cam-car) steer the car to the left or right? Is that steering suitable or not.

Table 4-6 How to use Collision Parameters to analysis the driver's behaviour

The analysis of table 4-7 was applied to every road user in the vicinity of the cam-car. So, if there are two road users that researchers are interested in, two records of tables will be generated. This analysis provided an in-depth understanding of risk assessments of surrounding road users.

Parameter	Description
Speed	This road user's speed is defined as high, medium, or low according to the traffic environment and in relation with the cam-car driver.
Distance	It describes the relative distance from the cam-car, include far away, close, or nearby.
Trajectory	It includes parallel, left to right, right to left, front to back, intersecting, towards the cam-car etc.
Location	It is described exactly as the location related to the cam-car

Table 4-7 How to use Collision Parameters to analyse other road users' behavior

CP analysis provides the basis information prioritization from the traffic situation perspective, in terms of risk assessments. To design a system that better matches and support drivers' mental representations of traffic situation. Further analysis of what goals a driver wants to achieve in certain traffic situations. Therefore, a further analysis of drivers' goal analysis in different traffic scenarios was carried out.

- **Drivers' goal analysis**

The method of drivers' goal analysis was developed in this thesis work and was inspired by Goal Directed Task Analysis (GDTA) (Endsley et al. 2003). In this thesis, the general steps to conducting a drivers' goal analysis include identifying the drivers' goals by observing how the driver operated the vehicle and estimated his/ her intended driving path from the naturalistic driving videos. Once the drivers' intended goal is understood, we break down the goal into sub-goals. As in the example shown below.

Main goal: a driver wants to change lane safely; Sub goal: determine the state of other lane (is the lane currently clear of vehicles?)

- Information Needs: Are there cars in front of me? (L1 SA: Perception)
- Information Needs: Are there any potential hazards moving toward my lane when I switch lane (e.g., pedestrians, animals, objects, other vehicles)? (L3 SA: Projection)

2) Focus group evaluation

The purpose of the focus group was to evaluate the principle of the system and UI design, thus two focus group sessions were conducted; one consisted of six HMI experts from an automotive company while the other consisted of six Interaction Design masters students. During the focus group study, several naturalistic driving videos were presented, followed by relevant discussion questions. The aim of using video clips was to initiate discussions regarding the information relevance for each traffic scenario and the road user prioritization. Along with the videos, first UI design was provided as means of discussion for confirming the findings from naturalistic driving video analysis, design ideas or getting possible new design ideas.

3) Design and driving simulator evaluation

Based on the naturalistic driving analysis results and feedback from focus group discussion, several prototypes were developed from paper to digital prototypes.

The evaluation was based on a driving simulator; the ATIS was tested with both Swedish and Chinese participants. The study utilized a 2 x 2 x 4 full factorial design, having country (Sweden/China), treatment conditions (without ATIS / with ATIS), and traffic incidents scenarios (Cut In, Intersection, Red Cab and Pedestrian) as independent variables. Driving performance data and the participants' opinions on the system were collected in a post-interview as dependent variables.

4.5.2 Findings

The results from the naturalistic driving video analysis and focus group discussion were summarized and used as design requirements for UI development and how the whole system should work:

- Colours: a light grey should be used for the Informative level to represent neutrality; amber should represent the Advisory level and orange or red for Warnings. The colours should provide a clear distinction between the Advisory and Warning levels.
- Icon: It is recommended to use only one icon that represents the vulnerable road users.
- Region: The interface should include the following regions: Front, Front right/left including the blind spots, Right/Left, Back right/left representing the rear view mirrors blind spots.
- Shape: The shape and its regions should represent the driver's view of the surroundings in a realistic manner. Circular forms should be avoided.
- Grouping: Pedestrians and bicyclists should form the vulnerable road users group and the system should react accordingly. Other road users should form the motorized road users group.

- Priority: Vulnerable road users have higher priority when presenting information. They are distinguished by the added vulnerable road user icon. The detection area for vulnerable road users should be larger and they have priority over the motorized road users on the interface. From the driver's input, parameters such as steering and acceleration should be more sensitive when encountering vulnerable road users.

In the figure 4-5, it shows how the design of ATIS works. The UI to the left presents information of three road users are at a distance (represented by the white lines) behind, to the back right and front right of the car. In the right UI, there is a pedestrian at a distance in front of the car, and another quite close in the right back blind spot. Moreover, some sort of vehicle is close to the car's right side.

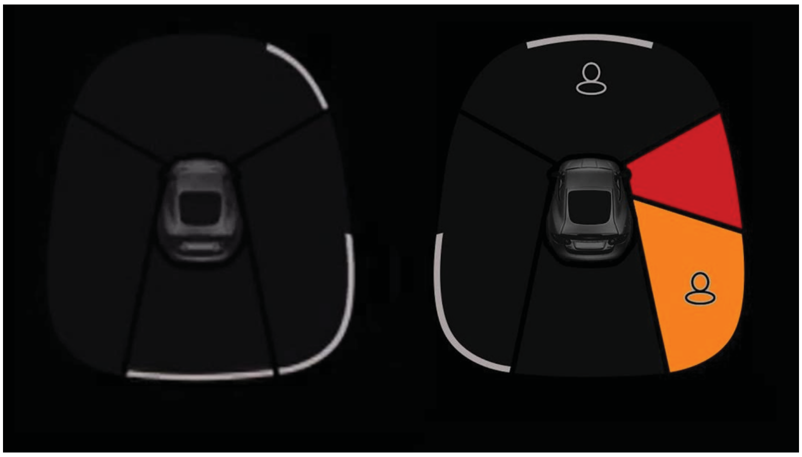


Figure 4-5 The second iteration of ATIS interface

The driving performance results showed that the driving patterns without using ATIS between Swedish and Chinese participants differed strongly, as can be seen in Table 4-8. Especially, when the situations involved pedestrians, the Swedish participants tended to brake or release the gas pedal as a means of staying out of a potentially dangerous situation; **a strategy related to changing speed (longitudinal control).** In comparison, the Chinese drivers were much more prone to steer first and then to slow down or speed up, i.e. change lanes and move on: **a strategy related to steering (lateral control)**.

When driving with ATIS, in general, similar driving behaviours were reflected in the results on driving patterns**. For the majority of Swedish participants, the first reaction was a longitudinal strategy (i.e. slowing down), whereas Chinese participants' first response was steering.** The significant differences found between groups indicate that even if **performance improved with the ATIS, it did not change or shape their original behaviours**. Swedish participants maintained their longitudinal strategy whereas the Chinese preferred lateral strategies.

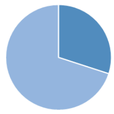
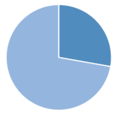
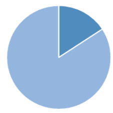
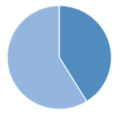
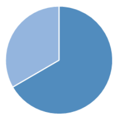
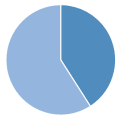
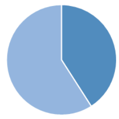
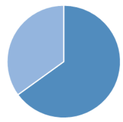
	Cut In	Red Cab	Inter-section	Pedestrian Crossing
SWEDEN				
	Lat: 30% Long: 70%	Lat: 28% Long: 72%	Lat: 16% Long: 84%	Lat: 41% Long: 59%
CHINA				
	Lat: 67% Long: 33%	Lat: 41% Long: 59%	Lat: 41% Long: 59%	Lat: 65% Long: 35%

Table 4-8 How Swedish and Chinese driving behaviours differed in terms of longitudinal (increasing or decreasing speed) vs lateral (moving sideways, e.g. when changing lanes) controls.

The Cut In scenario in the study exemplified how ATIS could be misused in different TSC contexts. Chinese participants' data indicated that the ATIS helped the drivers by making them aware of the cut in vehicle. But instead of braking or stopping for the vehicle to pass first, they utilized the information from the ATIS, in that they instead of stopping, switched to another lane to avoid the vehicle but were still be able to drive on, despite the fact that this behaviour is not encouraged from a safety perspective. So here, the interface actually encourages a lateral strategy for a driver preferring this. In contrast, Swedish drivers used ATIS information as a basis for keeping better safety margins with the road users around by slowing down more than anything else, which was the design intention of the system design.

Our study shows that Traffic Safety Culture is deeply rooted in the drivers' behaviours, and in conclusion we believe that one needs to think through this issue more than once before trying to design a more persuasive interface. It was already known that Traffic Safety Cultures strongly affect how drivers respond to a situation; we have also shown how different Traffic Safety Cultures can result in different driving strategies. Moreover, although it is possible to design a cross-cultural interface, drivers from different TSCs will still "game" the system. This implies that ATIS designers need to study and understand the motivation and intention of this utilization, in order to refine the ATIS further and anticipate the potential misuses in respect to a given TSC.

4.6 Study IX Evaluation of forward collision warning in Sweden and China

Paper E. Driver Response Behaviour Patterns and System Acceptance with Triggered Forward Collision Warning

In Studies VII & VIII, we found Swedish and Chinese participants have different response patterns to ATIS and traffic scenarios. The response patterns were identified and categorized based on drivers' first reaction operation, for instance, brake or steer. However, it is not clearly revealed how they differed in **reaction sequences** when comes to a typical car following scenario.

This study aims to figure out the cross regional difference of driver risk-avoidance behaviour patterns between China and Sweden in a typical FCW-involved scenario, car-following with front vehicle suddenly brakes.

4.6.1 Method

Sixty-two licensed drivers, 32 in China and 30 in Sweden participated in this experiment. The traffic density, country group, and FCW alarm timing were considered as independent variables. Behaviour data consisted of response behaviour patterns and collision indicator extracted from simulator data. Subjective data was system acceptance collected from questionnaire. Behaviour and subjective data were regarded as dependent categorical variables to characterize the cross-regional difference. The FCW system was realized by a combination of audio and visual display. The visual display was driven by a real Volvo car model of FCW system which consisted of a series of LED-lights mounted in front of the driver on the windscreen as a head up display. A single visual warning lasted for 2 s. The auditory warning was played with a 2.1 mini stereo. The tone was presented at 74.5 dB. The FCW system was triggered by specific threshold of time to collision (TTC) between the subject vehicle and the vehicle in front.

This study was carried out in similar simulator labs in both China, and Sweden. The simulator lab environment, including hardware and software settings, was identical in both sides. After instruction, participants were trained to follow the right lane and keep the speed at about 50 km/h. The FCW function was informed to participants and their understanding was guaranteed. The simulation scenario of each experiment was recorded. Those video clips were replayed to participants after their simulator experiment to get their system acceptance on each alarm timing (too early, acceptable, or too late).

4.6.2 Findings

There were 5 different behaviour sequences/patterns extracted from collected data, as defined in Figure 4-6. Those response patterns are 1) overtake directly, 2) decelerate, 3) steer followed by decelerating, 4) decelerate and then overtake and 5) steer, decelerate and then overtake. When the driver is warned of imminent collision with front vehicle, Pattern 1) is the situation where the driver wants to and succeeds in changing lane. Compared to Pattern 1), Pattern 3) describes a condition where the driver wants, however, fails to change lane. As indicated by Pattern 5), although there is adjustment, the driver manages to change lane successfully. In the Pattern 2) and 4), driver's first response is deceleration to avoid collision as warned by FCW. However, in Pattern 4), after slowing down, the driver takes the chance to change lane successfully.

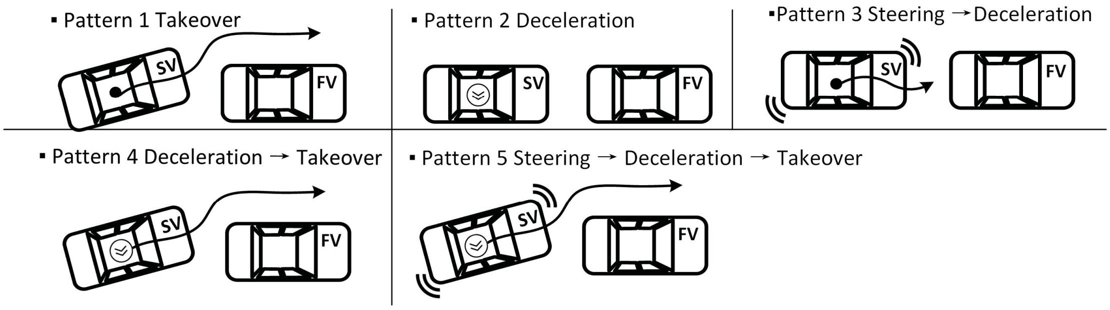


Figure 4-6 Driver response patterns

Country group had significant impact on the driver response patterns. Chinese participants overtook more frequently than Swedish participants did (42.6 % vs. 13.6 %). It is worth noting that for Chinese drivers, a considerable percentage of them regarded steering as, not only their first response intuitively, but also their maneuver strategy. The consideration behind such pattern was trying their best to change lane in response to triggered FCW. Unlike drivers in Sweden group, Chinese drivers take advantage of triggered FCW to increase driving efficiency, i.e., change lane to keep stable and relatively higher speed.

Regarding alarm timing, the design of a later FCW alarm timing was more preferred by Chinese drivers than Swedish drivers and it caused low system effectiveness (high collision probability) for Swedish drivers. This is reasonable because in China, there is a much higher traffic density, and drivers are likely to follow the car in front at a shorter distance. In these conditions, the warning triggered in Sweden may be regarded as a false alarm in China. Based on the obtained differences between the two countries, it further proved that the design of FCW needs to be modified for Chinese drivers.

5 DISCUSSION

This chapter aims to discuss the findings from nine studies in this thesis work. In the discussion, answers to the research questions are summarized. The external validities of the studies, methodology reflection and limitations are further discussed.

5.1 Traffic Safety Cultures affected drivers' information requirements

As the results from Study (I & II) clearly show, even though both countries have different Traffic Safety Cultures in terms of traffic situations and driving behaviours, **the traffic information needs for drivers were similar, especially in simple traffic situations where the driver only needs to interact with one other road user.** E.g. most participants agreed on the following points: 1) vulnerable road users such as pedestrians and cyclists should be given a high information priority; 2) blind spot information is needed; and 3) urgent information about items to the front of vehicle is generally appreciated.

However, **the differences were obviously more in complex traffic scenarios**, such as when interacting with multiple road users and/or under special road situations. Swedish participants require information mostly from the front side of vehicle, while the Chinese participants often seek for information not only from the front but also from the rear and side areas. These identified differences can be coupled to the countries' respective Traffic Safety Cultures. Drivers in Sweden respected and following traffic regulations; hence they trust and rely on other drivers to obey the same rules as well. Conversely, in China, as in other industrial developing countries with high-density traffic, various road users occupy almost all possible space on the road. In such situations, road users must not only consider the traffic regulations but also coordinate with one another. Therefore, to safely manoeuvre in such environment, each driver needs to be aware of the traffic everywhere around the car. The differences found in these scenarios imply how drivers from different regions expect the system to support their driving and such expectations are deeply rooted in their traffic safety culture.

5.2 Drivers from different regions utilized the ATIS differently

Keeping suitable longitudinal safety margin is expected as the desired response behaviour for ATIS, however, different traffic safety cultures yielded different driver response behaviour patterns. See Studies IV, V, VI, VII and VIII. The significant differences found between the two country groups indicate that even if driving performance (driving safety) was improved by the ATIS, it did not change or shape the drivers' original behaviours lying in their own traffic safety cultures.

Driver behaviour patterns as a response to ATIS are in line with drivers' preference on design requirements. Upon receiving given information from ATIS, the first reaction of the majority of Swedish participants' to the test events was a longitudinal strategy (i.e. slowing down), whereas Chinese participants' first response was lateral strategy (i.e. steering to another lane). In most test scenarios, Swedish drivers used ATIS information as a recommendation for slowing down to keep a better safety margin. The behaviour patterns also reflected in the requirement results that Swedish drivers are more interested in information regarding what is going on in front of them. In contrast, Chinese drivers change lanes if possible, assuming that the cars behind do not have time to brake, which might cause a serial crash. This phenomenon is a reconstruction of how some Chinese drivers drive to prevent themselves being cut-in or getting stuck in traffic; always try to change lane and find their way out. The similar results can be found from Özkan et al. (2006)'s comparison study between six European countries.

The different ATIS utilization strategies between two country groups were obviously displayed in Cut In scenario in Study VII & VIII and car following scenario in Study IX. For Chinese participants, the ATIS and forward collision warning helped by making them aware of the event vehicle. Instead of decelerating or stopping for the vehicle to pass first, they utilized the information, to switch to another lane which they knew was empty through the ATIS display. In both Cut in scenario in Study VII, VIII and car-following scenario in IX, if there is no oncoming traffic in the left lane, then changing lane would be the prior option for the Chinese drivers. They tried to avoid approaching the vehicle but still to be able to drive on, despite the fact that this behaviour is not in line with the original system design objective and safety perspectives. On the contrary, Swedish group drivers responded to ATIS information in a way that is in line with the original system design objective and safety perspectives. As a result, the interface actually encourages a lateral strategy for a driver who prefers this.

To sum up, the notion of "safe behavior" may differ from region to region. If an emergency brake will lead to a serial collision, it might be better to change lanes. It raised a number of design questions here. 1) What does "safe driving" entail in different regions? 2) Can we design a system in such a way that we can persuade driver behaviour towards the assumed safe behaviour? We are no longer certain that this is either possible or wise. The findings in this thesis show that Traffic Safety Culture is more deeply ingrained in the drivers' behaviours than we thought. Furthermore, the "golden rule" for a persuasive design is to never seek to persuade anyone of something they themselves would not consent to be persuaded of (Khaled et al. 2006). So as with any type of persuasion, while the persuasive intent of a persuasive technology will never be value free, it is the responsibility of the designer to design ethically and to support the drivers with safe driving.

5.3 Recommendations on cross-regional ATIS design

When transforming ADAS for use in multiple markets, it is not sufficient to just take visible or surface issues for localization, such as language, colour or shapes. Several studies have pointed out, if the purposes or functions of systems do not match local drivers' expectations, of what the system should or might do, the system usability will be highly impaired and result in low user acceptance(K. L. Young et al. 2012; Kristie L Young et al. 2012; Lindgren et al. 2008). An adequate localization should enable drivers to feel that the system was designed to support them to fulfil their goals in their everyday driving experience. It should take into consideration what information they require and how do they behave when interacting with other road users in their everyday driving context.

Driving is a complex and continuous process that involves visual perception of physical roadway objects and own vehicle states, information processing, decision making and the performance of actions (Endsley 2016; Kaber et al. 2012). Driving task consists of interactions with two dimensions: time and space. In this research, information presentation timing belongs to time dimension, and traffic complexity could be regarded as space dimension. From requirement to evaluation studies, how those two dimensions effect on design requirements and driver response patterns are revealed through cross-regional comparison. The hypothetical relationship between those factors is illustrated in figure 5-1.

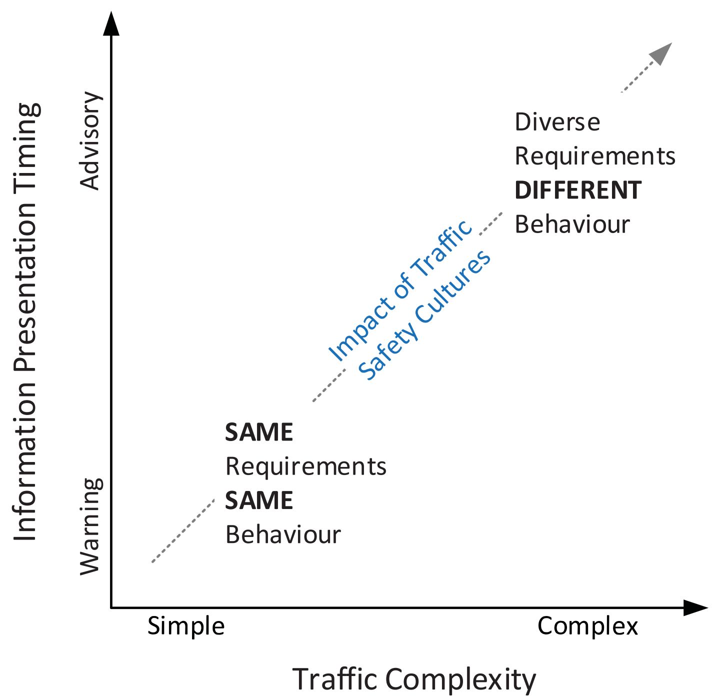


Figure 5-1 Hypothetical Traffic Safety Culture (TSC) impact on drivers' design requirements and response patterns, as the degree of information presentation timing and traffic complexity is increased.

Between two region groups, when the level of traffic complexity and information presentation timing increase, the similarity of drivers' information requirements decreases and the diversity of response patterns increases. This implies that for simple traffic or warning situations, cross-regional adaptive design can start with one region group to understand and elicit the fundamental design requirements, e.g. alert or inform about emergency events, vulnerable road users and etc. For such low complexity scenarios, adaptation design could focus on understanding the risk perceptions in order to adjust system parameters. For instance, the braking distance of the Automatic Emergency Braking (AEB) system can be varied between Swedish and Chinese markets, since the risk perception between these two groups varies largely, as has been proven in this research.

Regarding design for advisory information to support drivers' high level SA, and the traffic situations becoming complex, with multiple road users involved. Drivers from different regions may result in different strategies when handling the situation, as per dependent on their respective Traffic Safety Cultures. For instance, Swedish drivers preferred to keep longitudinal safety margins where Chinese driver are prone to seeking for alternatives to maintain their driving efficiency rather than slowing down. To succeed with a cross-regional design, this research suggests that a comparison study should be conducted to understand drivers' strategies and motives during complex traffic situations. If there is a mismatch between the information provided by ATIS and the drivers' expectations, it increases the tendency for the drivers to consider the information as a false alarm and is likely to undermine acceptance and lead to disuse. Parasuraman & Riley (1997) and Lee (2008) have also emphasised that the trust between operators and automations is particularly important for the success of the human-automation interaction. Many problems with automation stem from the mismatch of the expectations that designers have regarding the need to support an operator.

5.3.1 Design recommendations on ATIS design

In this research, two information modalities were explored: visual and auditory. Comparing the results in different studies, one general conclusion can be drawn between visual and auditory modalities that participants' information requirements are modality independent. The fundamental requirements are consistent regarding road user grouping, information prioritization or preference of information from different sectors in both groups. The difference between modalities is manifested in users' preference on interface design, for instance, information presentation timing and number of information attributes. The following Table 5-1 sums up the requirements and user interface design specification between visual and auditory modality, as found in the all studies of thesis work.

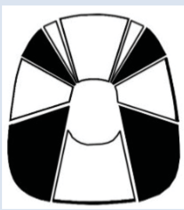
Design Recommendation	Visual Modality	Auditory Modality
UI design for information levels	The colours should provide a clear distinction between Advisory and Warning levels.	To avoid information overload, only advisory and warning levels should be presented.
Road users grouping	Pedestrians and bicyclists should form the Vulnerable RU group (VRU); Other RU will form the motorized RU group.	
UI design for grouping	VRU should be visualized. As opposed to VRU, motorized RU don't have icon, it makes it easier to prevent information clutter.	All RU should be represented by one earcon to reduce the complexity of the system. But VRU should be assigned a higher information priority than motorized RU.
System algorithm	The system should use time to collision for risk assessment. Drivers' vehicle control inputs should be applied to determine drivers' intentions, e.g. steering, braking and accelerating.	
General information priority	- VRU should have higher priority compared to motorized RU, in terms of larger detection area - VRU situated on the road should be set to a higher level of threat than other RU, regardless of their status, moving or static - Crossing events should have higher priority	
Directional information	The interface should include several regions. The front right/left blind spots should present VRU that can be hidden by A pillars. 	Spatial sound cues work ideally in situations involving single RU in the front and side sectors. In situations with several RUs and RU approaching from rear, spatial sound cues can be confusing, should be supported with visual information.

Table 5-1 Recommendations for ATIS Information Design

5.4 Methodology reflections: utilization of naturalistic driving videos for design

In this thesis work, solid examples have been provided regarding using naturalistic driving videos as design materials at different stages of IVIS design. The naturalistic driving videos have a continuous view into the happenings in and around the vehicle; these videos provide good resources for the designers to gain insights of what happens, why and how it is carried out in natural driving environments. With such a perspective, designers can study how drivers interact with other road users and traffic environments, formulating a holistic understanding of what information is needed in order to support the driver's goals and decisions making in various traffic situations.

Design scenarios set constraints of what we design for, it is important to select and design the scenarios in line with the design aims (Rosson et al. 2002). Since the aim of ATIS was to present situation information during non-critical situations, it often involves multiple road users simultaneously, the most interesting design questions were how to prioritize and visualize multiple information at once. Most previous studies were focused on conflict zone with one road users involved e.g., pre-crash scenarios typology defined by National Highway Traffic Safety Administration (Najm et al. 2007). Therefore, there was not much prior knowledge regarding scenario selection to support the objectives of ATIS design.

- **Scenario selection**

In this thesis work, when observing the videos from multiple countries, the traffic complexity between countries usually varies largely, e.g., separated vs. mixed traffic, simple vs. complex situations. To better cover typical scenarios in both countries, the traffic scenarios should be selected spread evenly, with different traffic complexity degree and road users' types. In order to make sure the selections are not biased by TSC background of individual researchers. A number of expert discussions are recommended for the final selection.

- **Naturalistic driving videos support user involved studies**

In the focus group studies in this research, naturalistic driving videos are applied as dynamic storyboards for focus group discussion to bring the common understanding of the design contexts. It helps to create a more immersive experience, brings the discussions focus onto the traffic events in the videos, and engages the participants to discuss and reflect how they would perform under such situations.

- **Naturalistic driving videos support expert assessment**

Drivers' preference for information prioritization was studied by using Video Collision Parameters (CP) analysis and drivers' goal analysis. The CP method is developed with inspiration from TTC (Hayward, 1972; Laan, 1997). CP analysis helps designers to develop a clear understand as to what supporting driver safety means in a particular situation, for instance, other road users hazards level in relation to the drivers. Drivers' goal analysis is inspired by goal oriented task analysis (GOTA)(Matthews et al. 2001). The drivers' goal analysis focuses on the goals the drivers want to accomplish and the information needed in order to achieve those goals. Performing a comprehensive CP and driver's goal analysis takes extensive time and effort, even then, a fair degree of subjectivity can exist on the analysis, and this is the common problem with all task analysis methods. To ensure the analysis is as complete & accurate as possible, the generated information prioritization should be carefully reviewed and discussed with several focus group discussions in the research.

5.5 Limitations and future work

Cross-regional comparison on design requirements and driving behaviour response when using ATIS were explored in this thesis work. There are some potential limitations of this research are discussed in the following section.

- **Country selection and TSC dimensions**

Although Sweden and China, as cross-regional comparison targets, are quite representative, more comparison studies between other countries are needed to improve the generalizability of the findings in this thesis work. There are two cultural dimensions (traffic complexity and information time) that were sensitive to regional difference on information requirements and behaviour patterns. In this study, the traffic complexity was selected as the target TSC dimension, in terms of number of road users involved in the traffic scenarios. Although such dimension distinguished the two countries significantly, in the future study, more factors regarding traffic scenarios should be studied, for instance, types of road, speed, distance gaps between drivers and other road users and etc.

- **Using naturalistic driving video for design**

One important question remains to be addressed. Once a large body of naturalistic driving videos has been collected, which videos should be analysed? In current research, the criterion for video selections were set to cover the typical normal traffic situations in both countries in our video database; in addition, the level of traffic complexity was considered as a second criteria. However, from the video observation and extraction results, it is clearly indicated that the incidents occurred often in the Chinese videos than Swedish ones, so it directly resulted the proportion of extracted videos between China and Sweden is uneven in our video database. Most extracted Swedish videos are under simple traffic situations. This uneven proportion in some degree reflected the traffic characteristic between Sweden and China, but the caused different familiarity might also influence the results and opinions when Swedish experts and participants reviewed the videos for design requirements and design. Therefore, it’s recommended to use drivers and designers who have experience about TSC in target regions.

Naturalistic video observation, extraction and analysis are labour-intensive. To make sure the results is unbiased and valid, the videos from different countries should be comprehensive.

- **Selection of target population**

In this thesis work, the target participants selected were potential users of premier cars in both countries, therefore, the participants from both countries had similar education background, and incomes. It would be interesting to study the regional differences between other driver segments to examine how other factors influence regional difference. For instance, driving experience, age and gender.

- **Settings of information presentation timing levels**

Compared to warning level (TTC = 3 s), the information presentation timing was doubled and tripled for advisory and informative level respectively. However, the safety margins of safety and comfort zones are individually different and contextually dependent influenced by a number of factors. Although the settings were based on thorough literature review and iterative testing on a driving simulator, it still needs further validation and adjustment for the real-world application of system design. In the future, to refine the safety margins for safety and comfort zones, larger-scale empirical studies to test drivers' subjective feedback and behaviour patterns in different types of traffic scenarios should be carried out. More other system parameters should be integrated into the algorithm to enhance the accuracy of information providing e.g., considering drivers' attentional status.

- **Driving simulator as experiment environment**

This study is based on driving simulators where the participants were not distracted by any secondary tasks and only drove for an hour. Although the driving simulator is safer which allows a researcher to investigate a wider range of driving scenarios, it still lacks the complexity and workload of a real driving situation. In addition, the subjective feedback and driving performance could be different after a long period of use. In addition to addressing these limitations, the first would be to conduct in a higher fidelity driving environment and to follow the drivers' behaviour and acceptance changes over a period of time.

6 CONCLUSION

In this thesis work, several design concepts of cross-reginal Advisory Traffic Information Systems (ATIS) were designed and evaluated. The systems aim to provide feedforward information to support drivers' situation awareness and decision making during manoeuvres.

To gain knowledge of how to do cross-regional design on ATIS, this research carried out nine studies to study the regional difference on information requirements (user studies) and drivers' response behaviour when utilizing ATIS (driving simulator studies) between Sweden and China. The research followed a human centred design (HCD) process and naturalistic driving videos were applied throughout the whole design process to address the contextual constraints. Within the scope of the findings from nine studies, the following conclusions were obtained:

1) TSC affects drivers' information requirement and behaviour patterns

Even though both countries have different Traffic Safety Cultures (TSC) in terms of traffic situations and driving behaviours, they share common information needs, especially in simple situations involving only one other road user. As most participants agree that vulnerable road users such as pedestrians and cyclists should be given a high information priority; blind spot information and urgent information from the front are generally appreciated. However, the differences were obvious in more complex traffic scenarios, e.g. when interacting with multiple road users and/or under special road situations, e.g. roundabouts. Swedish participants require information mostly from the front, while the Chinese participants often require information not only from the front but also from the rear and side areas.

Driver behaviour patterns as a response to ATIS are in line with drivers' requirement findings. The significant differences found between the two country groups indicate that even if driving performance (driving safety) was improved by the ATIS in general, it did not change or shape drivers' original behaviour stemming from their own TSCs. As the first reaction to an incident, the majority of Swedish participants maintained suitable longitudinal distance, whereas the Chinese participants' first response was a lateral strategy (i.e. steering to another lane).

Moreover, although it is possible to design a cross-regional interface, drivers from different TSCs will still "game" the system to utilize the support to fulfil their intended strategies. This implies that ATIS designers need to study and understand the motives of these utilizations, in order to refine the ATIS further and anticipate the potential misuses in respect to a given TSC.

2) Design implications: the similarity of drivers' information requirements and response patterns decreases with increasing level of traffic complexity and information presentation timing.

Based on the comparisons of information requirements and driving behaviour between the two groups, a hypothetical relationship was drawn: when the level of traffic complexity and information presentation timing increase, the diversity of drivers' information requirements and response patterns increases among different TSCs. This implies that during simple traffic or warning scenarios, cross-regional adaptive design can start with one region group. It suggests to first focus on eliciting the fundamental information requirements of one regional group to determine the essential functional objectives. Then study the risk perceptions between regional groups to optimize the system parameters accordingly. For instance, different alarm timing for different forward collision warning (FCW) cross-regionally.

Regarding design for ATIS to support drivers' high level situation awareness (SA) under complex traffic scenarios, drivers from different regions showed different strategies when handling a traffic scenario. Different strategies directly influence what information a driver require from an ATIS. To make a cross-regional design successful, the research suggests that a comparison study should be conducted to understand drivers' strategies and motives in complex traffic situations. If there is a mismatch between the information provided by the system and the drivers' expectations, such a mismatch increases the tendency for the drivers to consider the information as a false alarm and therefore, it is likely to undermine acceptance and lead to disuse.

3) Naturalistic driving videos are promising design materials for ATIS design

In this thesis work, solid examples have been provided regarding using naturalistic driving videos as design materials at different stages of ATIS design. Naturalistic driving videos are applied as dynamic storyboards for focus group discussion to bring the common understanding of the design contexts. From a user's perspective, it helps to create an immersive experience, bringing the discussion's focus on the traffic scenarios in the videos, and engages the participants to discuss and reflect how they would perform in such situations. From the expert's perspective, two design requirements analysis methods, video collision parameters and drivers' goal analysis, were combined to support information requirements and prioritization. Using naturalistic driving videos in the expert discussion promotes design efficiency compared to other methods, e.g., field observation. In addition, it helps to produce concrete information prioritization results that can be used directly to guide system design.

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