

Cooperative speed assistance : interaction and persuasion design

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Cooperative Speed Assistance

Interaction and Persuasion Design

Qonita Shahab

PhD committee members:

prof.dr.ir. J.H. Eggen, Eindhoven University of Technology (promotor)
dr. J.M.B. Terken, Eindhoven University of Technology (copromotor)
prof.dr. A. Schmidt, University of Stuttgart
prof.dr. M.H. Martens, University of Twente
prof.dr. P. Markopoulos, Eindhoven University of Technology
prof.dr. K.A. Brookhuis, University of Groningen
prof.dr. C.J.H. Midden, Eindhoven University of Technology
prof.dr.ir. A.C. Brombacher, Eindhoven University of Technology (chairman)

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Propositions

accompanying the thesis

Cooperative Speed Assistance Interaction and Persuasion Design

by Qonita Shahab

1. The task of an in-vehicle advisory system is a combination of providing the right information at the right moment and displaying the information to the right person, because this combination is what converts the information into advice. [this thesis]
2. To understand the decision a driver takes to perform a traffic manoeuvre, we need to know the driver's motivation, ability, and opportunity to act in the situation at hand. [this thesis]
3. Driving can be considered a kind of game, where drivers constantly maintain the game flow by facing the imminent risks induced by road conditions and other road users. [this thesis]
4. There is a thin line between persuasive technology and communication technology, because the former is used to persuade users using designed elements and the latter is used to communicate messages that can be persuasive. [this thesis]
5. Quantifying human behaviour is not a trivial process, because unconscious and irrational cognitive processes may influence observable human behaviour.
6. Experience is best learned from first-hand accounts; it may not be possible to obtain a valid forecast of a certain experience from users unless they previously interact with the system in an appropriate context.
7. Science is about discovering new things and spreading that knowledge around. [quoted from Jonathan Eisen in a video <http://www.phdcomics.com/tv/#015>]
8. Doing a PhD is a way to understand better about the Self. [definition of Self by C.G. Jung]
9. Optimism is in the eye of the beholder; being optimistic to someone may look like being ambitious to others.
10. Like in a Pac-Man game, while the professors are freeing precious empty slots in their schedules, it is the PhD students' task to prevent them from doing so.

Cooperative Speed Assistance

Interaction and Persuasion Design

PROEFSCHRIFT

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Copromotor:

dr. J.M.B. Terken

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Summary

Cooperative Speed Assistance: Interaction and Persuasion Design

Highway traffic congestion can be caused by unstable traffic flow, as a consequence of differences in the speed and acceleration/braking of vehicles on the road. To reduce these differences between vehicles, the Connect & Drive Project was initiated for developing a Cooperative Adaptive Cruise Control (C-ACC) system dealing with limitations of Adaptive Cruise Control (ACC). This system employs communication between vehicles to coordinate their speed with each other in order to optimize traffic flow. Since the optimal traffic flow can only be achieved if all vehicles are equipped with a C-ACC system, which may take considerable time, the Connect & Drive Project also proposed an aftermarket system. This system may be marketable more easily than built-in systems and may be easily retrofitted to current vehicles. Technically this system does not have access to automatically control the vehicle's system. Instead, drivers receive advice from this system about speed, acceleration, and/or distance to the preceding vehicle (time gap).

This thesis proposes the design for an aftermarket, easily retrofitted, advisory system, called Cooperative Speed Assistance (CSA). The objective of the work presented in this thesis was to design a user interface for the CSA system that is sufficiently alerting but not distracting (Interaction Design) and to study how to maximize the driver's compliance with the advice (Persuasion Design). For the Interaction Design, we studied the What, When, How of a speed advice, the type of the advice (speed or acceleration), and the design of the multimodal interface (visual and auditory information display). For the Persuasion Design, we studied the literature on individual differences among drivers in speed-related behavior, conducted a questionnaire study in order to confirm these differences, and evaluated the persuasion design with a serious game experiment using the CSA system combined with a navigation system. The contributions of this thesis are summarized in the following paragraphs.

Advisory System for Cooperative Driving. This contribution is based on the design process of a speed advice concept consisting of three states (Too Slow, Appropriate, Too Fast). In the exploratory study described in Chapter 2, we studied the What, When, How of a speed advice by conducting focus groups and testing two prototypes (advice only and advice plus additional information) in a driving simulator. The prototype with the additional information was rated by drivers as more helpful in recognizing the urgency of advice. Drivers considered the three-state concept as more useful than the existing system on the highway, in terms of the relevance of the advice. As it is known today, the dynamic speed limit information on the electronic message boards above highways display one-size-fits-all

information that may not apply to all drivers. A compliant driver may need confirmation, but a non-compliant driver may need repetition. We followed up this finding by testing two prototypes (speed advice and acceleration advice) in a driving simulator, as described in Chapter 4. Based on the results, we do not recommend for using only speed advice or only acceleration advice, because each type of advice created different effects on driver's behavior. It was found that speed advice allowed drivers to have freedom in the implementation of the advice, and acceleration advice allowed drivers to have precision in distance keeping. Acceleration advice caused less speed fluctuation in heavy traffic and more stable distance keeping, but it caused more frequent throttle pedal changes (may increase fuel consumption). It was also found that drivers can drive with a shorter time gap while using their preferred type of advice, leading to a more efficient traffic flow.

Portable In-vehicle System for Cooperative Driving. This contribution is based on the design process of a multimodal interface that consists of visual and auditory information display. In the study described in Chapter 2, we explored the visual and auditory information display. The visual information was displayed on a peripheral visual interface (glanceable display), in order to enable drivers to use their peripheral vision (minimum glances). After testing in a driving simulator, we found that the auditory information needed a redesign. We created two simple tone concepts and tested the two concepts in a driving simulator, as described in Chapter 3. Both concepts were rated as requiring low mental effort and moderately helpful in recognizing urgency. The driving simulator test results are summarized in Chapter 5. The summary generated insights for using the visual information for presenting the speed advice as long as the advice applies, and the auditory information for presenting the distance advice only when it is critical. Based on the results of three driving simulator studies, we found that by using the peripheral vision drivers were neither distracted nor annoyed by the continuous display of the speed advice, but were still reasonably alerted. We concluded that the design of this multimodal interface displaying only visual and auditory information allows the CSA system to be easily retrofitted to any vehicle. It can also be easily deployed in smart phone applications, with present day wireless technology that has already made possible the communication between vehicles and road infrastructure.

Tailored Persuasion Strategy in the Driving Context. This contribution is based on the investigation results on individual differences among drivers that are relevant to complying with a speed advice. Based on literature study as described in Chapter 6, we decided to try to persuade drivers to comply with the advice of CSA by using monetary rewards, immediate feedback and positive feedback. While the monetary rewards are targeted at extrinsic motivation, we decided to target intrinsic motivation as well. Literature study on intrinsic motivation showed individual differences among drivers in terms of attitude and behavior in speed related

situations. From the literature, personal values in driving were derived: safety, being responsible to others, emotional state like having fun and feeling relaxed, eco driving issues, time saving, and money issues. In order to confirm these personal values, we designed a questionnaire that reports behavior and its underlying reasons, called the Personal Driving Values Questionnaire (PDV-Q), as described in Chapter 7. After validating with 250 drivers, 6 factors (Sustainability, Relax, Fun, Safety, Time, Fines) were extracted as the personal values in driving. Through PDV-Q we learned the distribution of profiles among drivers, suggesting that PDV-Q can be used for understanding the users of other traffic applications. For example, we found that most of the 250 drivers displayed a Safety or a Fines profile. It was found that older drivers are more likely to have a Safety profile and less likely to have a Fines profile.

Persuasion Design for Cooperative Driving. This contribution is based on the investigation results on persuading drivers to comply with a speed advice in order to participate in cooperative driving. Because of the individual differences among drivers, we need different persuasion strategies. To determine which persuasion strategy a driver is most susceptible to, in this thesis we defined the persuasion profile of the driver by finding his/her strongest personal driving value. A persuasion strategy was then represented by a persuasive message addressing the personal driving value. As described in Chapter 8, the use of persuasive messages was tested using a serious game experiment, to overcome the limitation of a driving simulator for studying behavior change. The game included real monetary rewards, and there was a bonus level where the drivers experienced Adaptive Cruise Control (ACC). The results indicated that drivers were already compliant with the speed advice, and persuasive messages (both monetary and non-monetary) did not increase their compliance. The mediating role of the individual differences on the effectiveness of the persuasive messages could not be confirmed, because the behavioral response to each message was not persistent for each driver. Based on interview results, drivers considered monetary rewards and using ACC as persuading them to participate in cooperative driving. The context also played an important role in influencing drivers' attitude toward cooperative driving. Examples of contexts that favor drivers' participation in cooperative driving: when not in a hurry, when the recommended speed is not too low, and if everybody else is doing it. In the study described in Chapter 2, drivers considered the additional information (such as a traffic jam ahead or an accident ahead) provided by the CSA prototype as motivating them to respond to the advice. Combined with the results of the serious game experiment, we concluded that the additional information should be relevant to the traffic condition.

1

Introduction

1.1. Background

1.1.1. Problem

Highway traffic congestion is a well-known problem worldwide. Several attempts to reduce traffic congestion were enforced, such as improving traffic signal controllers, adaptable highway signs, and rerouting rush hour traffic (Martin, Marini, & Tosunoglu, 1999). In order to improve the technology for solving traffic problems, the Intelligent Vehicle-Highway System (IVHS) was initiated (Bishop, 2005). In an IVHS system, wireless networks are the foundation of communication among vehicles and between vehicles and road infrastructure units. IVHS was then renamed with a bigger umbrella term: Intelligent Transportation System (ITS) (Nowacki, 2012). ITS utilizes telecommunications, electronics, and information technologies for road transport and its interface with other modes of transport, in order to improve traffic efficiency and reduce environmental impact (European Union, 2010).

Applications of ITS for road safety are for example intelligent speed adaptation and intersection crash avoidance. For solving traffic congestion problems, ITS technology is used for enhancing traffic flow, because a smooth traffic flow is important for preventing traffic congestion. As represented by the term ‘Phantom traffic jam’ (or ghost traffic jam), traffic congestion can happen even if there are no obstacles or blockages on the road. A study on the phantom traffic jam phenomenon (Sugiyama et al., 2008) confirmed that the difference in speed is one of the causes of traffic jam. If vehicles coordinate their speeds with each other, traffic shockwaves are minimized and optimal traffic flow is achieved. The cooperation factor is essential, and thus it is important to investigate how cooperation can be enabled. Cooperative driving as an ITS application is the context of this thesis. As a consequence of a newly developed technology, we need to make sure that people will use the system.

The work in this thesis was initiated in the context of the Connect & Drive project, which developed a technology for cooperative driving: Cooperative Adaptive Cruise Control (C-ACC) (Connect & Drive Project, 2008). In a first generation cruise control, drivers can set a fixed speed and the vehicles automatically keep the set speed. In the second generation cruise control called Adaptive Cruise Control (ACC), drivers can also set a minimal distance to the preceding vehicle. ACC utilizes RADAR/LIDAR¹ to detect the preceding vehicle in order to maintain a minimal distance, and the vehicles automatically adapt the speed accordingly. C-ACC is the next generation of ACC. It

¹ RADAR (RADio Detection And Ranging) units transmit radio waves at a designated frequency that reflect off of a moving target vehicle and return to the unit. LIDAR (LIGht Detection And Ranging) units send out a laser beam. The initial bursts of light allow the unit to determine the distance to the target vehicle by calculating the time it takes the beam to reflect off of the vehicle and return to the unit.

utilizes wireless communication allowing speed adaptation with non-adjacent vehicles and communication with the infrastructure.

In cooperative driving, the traffic consists of platoons of vehicles, where each platoon consists of a number of vehicles with an equal distance between them. These vehicles continually adapt their speed with each other in order to minimize the instability of the platoons. Using C-ACC, this speed adaptation is automatic, i.e. done by the cruise control system of each vehicle. The ideal condition is that C-ACC would allow a smaller distance between vehicles and smaller variability in speeds among the vehicles. This causes the vehicles to have higher average speeds resulting in a better traffic flow.

Imagine that traffic jams would disappear in the future. Ideally, there is a very big space to expand highway capacity in order to allow more vehicles to travel efficiently through the highway. One way to increase highway capacity is achieved if all vehicles in the traffic are equipped with the C-ACC system. The larger the number of vehicles in the traffic using C-ACC, the better impact to the traffic flow (van Arem, van Driel, & Visser, 2006). In this scenario, traffic jams can be reduced up to 50 % (van Arem, Jansen, & van Noort, 2008). According to (van Arem et al., 2006) a low penetration rate of C-ACC (less than 40%) does not have an effect on traffic flow, while a high penetration (more than 60%) does have a benefit on traffic stability.

1.1.2. Solution

How do we increase the penetration of C-ACC technology in the market? These days even ACC is not widely available in passenger cars. It is still a costly technology, and the installation of cruise control is only possible by the vehicle manufacturers (in-vehicle built-in systems). It takes time for the C-ACC technology to mature for easy adoption by vehicle manufacturers. As soon as the traffic infrastructure is ready, existing (older) vehicles also need this technology. Therefore, the technology needs to be easily retrofitted to current vehicles and low cost to build.

Toward a higher penetration rate, we propose an aftermarket device, which would be marketable more easily than in-vehicle built-in systems. For easy retrofit to current vehicles, technically this device does not have access to automatically control the vehicle's system. In other words, this device uses human-in-the-loop control on the braking and acceleration of the vehicle. Moreover, the system should be nomadic and deployable in other mobile devices such as smart phones.

This thesis focuses on the design of a nomadic Advanced Driver Assistance System (ADAS) to be used in cooperative driving. The history and state of the art of cooperative driving technology and ADAS technology are discussed in the following section.

1.2. State of the Art

1.2.1. Cooperative Driving

In an ITS application, vehicles can communicate with each other (V2V) and vehicles can also communicate with highway infrastructure (V2I). In cooperative driving, vehicles can communicate their speed/acceleration/distance with each other, receive dynamic speed limits from the highway infrastructure, and send their own speed/acceleration/distance to the highway infrastructure. The goal of this communication is to create cooperation among vehicles, where their speeds are rendered as uniform as possible. How this communication works is illustrated in Figure 1.1.

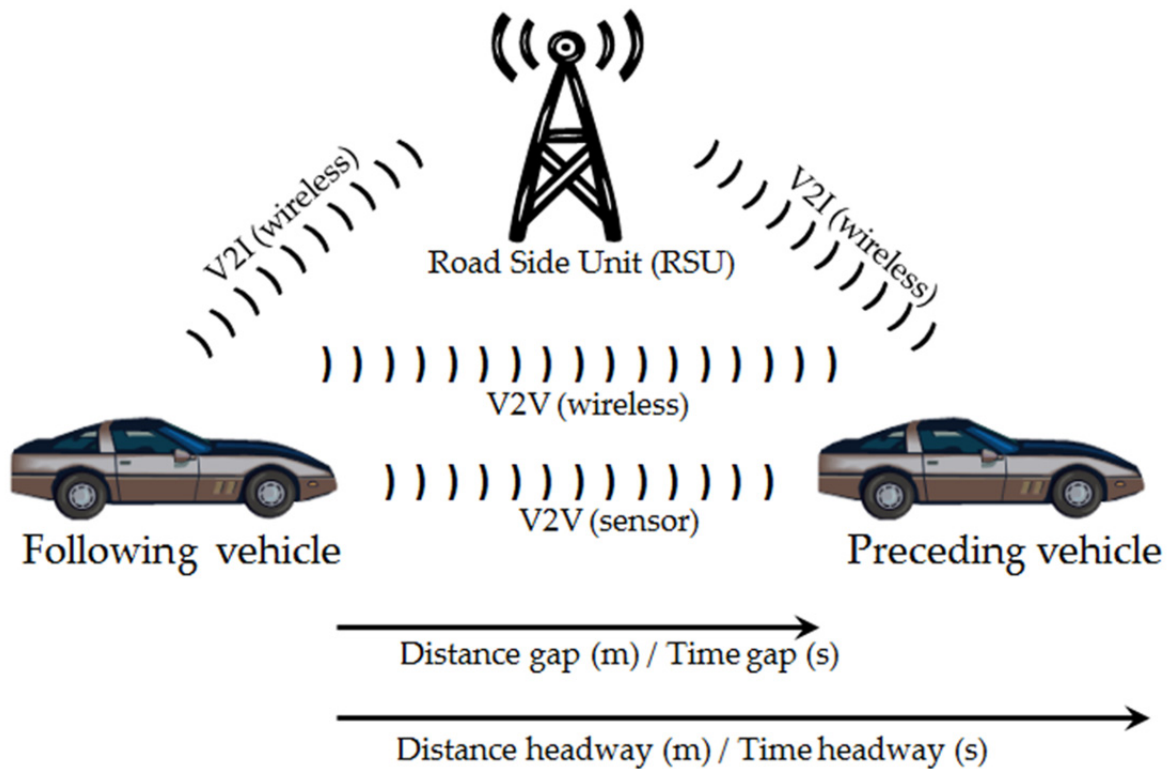


Figure 1.1. Communication in a cooperative driving system: V2V (Vehicle to Vehicle) communication allows a vehicle to communicate not just with the directly preceding vehicle, but also with other vehicles ahead and behind; V2I (Vehicle to Infrastructure) allows a vehicle to communicate with Road Side Units in order to get updates about the traffic condition. The vehicle is said to have V2X (Vehicle to Everything) communication system.

In the United States, cooperative systems have been investigated in an ongoing project called PATH program since 1986. Apart from developing technology for IVHS and then ITS, the program also tried to bridge the cultural gap between involved institutions such as academia and different state departments of transportations. Since their interest was to address the transportation needs where

physical infrastructure cannot be expanded, the project has a strong emphasis on automated highway systems. This includes traffic management, traveler information systems and road electrification (Shladover, 2009).

In Europe, several projects on cooperative driving have been carried out earlier than the Connect & Drive Project. The COOPerative systEms for intelligent Road Safety (COOPERS) Project (2006-2010) focused on the development of telematics applications on the road infrastructure (COOPERS Project, 2010a). The goal of the project was to enable cooperative traffic management between vehicles and infrastructure, while reducing the gap between car industry and infrastructure operators. In three separate test sites, the project tested the system with 115, 43, and 10 drivers for a few hours each (COOPERS Project, 2010b). After driving, the test participants filled in a questionnaire about the system. They indicated that accident warning was the most important information that they would like to receive. This was followed by traffic congestion warning, roadwork information, and weather condition warning as the second most important information that they would like to receive.

The COOPERS Project was carried out at approximately the same time as the CVIS (Cooperative Vehicle Infrastructure Systems) Project and the SAFESPOT Project. The CVIS Project (2006-2010) aimed for developing technologies for vehicles to communicate with other vehicles and the road infrastructure. In 2007, this project conducted a survey on 7687 European drivers (CVIS Project, 2007) for the user acceptance of ITS applications. The questionnaire asked drivers to evaluate the present and future ITS applications as well as the messages presented by such applications. The top five desired messages by users were: Warning about Ghost Drivers, Warning message 5km ahead of accident, Current traffic flow, Speed limits, Messages to speed up / slow down to regulate traffic flow. All of these messages (except Ghost Drivers) are relevant to highway congestion, where traffic jams are among the problems that disturb traffic flow.

The SAFESPOT Project (2006-2010) also aimed for developing V2X technologies, but the safety issue was emphasized. The project investigated a combination of the information from vehicles and from the infrastructure for critical areas such as road intersections in urban traffic and black spots in the highways (SAFESPOT Project, 2010). A similar but earlier project, PReVENT, was carried out between 2004 and 2008. The project developed technologies aimed for traffic safety applications for maintaining safe speed and safe distance, passing intersections safely, and avoiding crashes (ERTICO, 2010). COOPERS, CVIS, SAFESPOT and PReVENT collaborated to demonstrate how the developed systems work (SAFESPOT Project, 2010), in various occasions across Europe.

The SAfe Road TRains for the Environment (SARTRE) Project (2009-2013) is the latest European project aimed at developing technology for cooperative driving systems with an emphasis on automated vehicle control, just like the Connect & Drive project. The main goal of the SARTRE Project was to have vehicles drive together in a platoon with a lead vehicle (SARTRE Project, 2013). The demonstration was conducted with a lead truck, a following truck, and three following cars. The steering angle was limited by the power steering system (assisted steering). The public road test calculated up to 50% of reduction in headway-related accident by car drivers and 10% reduction in fuel consumption on the following cars. The system was considered as comforting, allowing drivers to do other things while driving.

The Connect & Drive Project (2008-2011) has successfully demonstrated an automated platoon of seven cars with a small time gap between them. During the demonstration, a platoon joining message was communicated, that a car could join as the fourth car in the platoon. When the first car made a complete stop, the following cars also made a complete stop even with a small time gap between them (Ploeg, Serrarens, & Heijenk, 2011). Compared to driving with ACC, the cars could drive at a shorter distance and still stopped safely.

As the technology for platoons of automated vehicles is different from the one where drivers are involved in controlling the vehicle, the Connected Cruise Control (CCC) Project (2009-2013) was initiated by the Dutch government. The goal of the CCC Project was to implement an in-vehicle telematics platform with a back office system collecting and processing traffic data. Because of the emphasis on the human-in-the-loop, a special driver advice module was implemented. The demonstration result showed that drivers appreciated the advice. The traffic flow simulations with advisory vehicles showed that the traffic delay could be reduced up to 30% (Connected Cruise Control Project, 2013).

1.2.2. Advanced Driver Assistance Systems

Advanced Driver Assistance Systems are meant to support drivers in order to have a higher safety, lower workload, or a fascination of use (Flemisch, Kelsch, Löper, Schieben, & Schindler, 2008). Various ADAS technologies employ different degrees of automation. According to Flemisch et al. (2008), vehicle automation is assessed along a continuum between 100% human control and 100% fully automated. In order to assess the future of ADAS along the continuum of automation, a European project (HAVEit Project, 2011) was carried out. The project investigated and demonstrated different conditions of driving from fully-manual, assisted, semi-automated, highly-automated, to fully-automated.

The projects mentioned in Section 1.2.1 have demonstrated the use of ADAS in improving safety and comfort. And as early as 1997, vehicle automation has been investigated as lowering mental workload (Young & Stanton, 1997). Mental workload is usually measured when a driver performs a secondary task while driving (Schaap, Horst, van Arem, & Brookhuis, 2009).

The C-ACC system demonstrated by the Connect & Drive Project was aimed at increasing safety and comfort. The system is an example of a semi-automated system, because it only takes care of the longitudinal control of the vehicles, where drivers still have to steer the vehicles (Shladover, 2009). A highly automated version of C-ACC is conducted with lateral control, so the drivers do not need to steer the vehicles. A fully automated version of C-ACC is the automated highway system, where drivers no longer need to monitor the system, and the system takes care of errors by returning to minimal risk condition (Gasser & Westhoff, 2012).

Referring to the literature by Flemisch et al. and Gasser et al. mentioned above, systems that advise and warn drivers fall into the assisted category. A study about Intelligent Speed Adaptation (ISA) separated four levels of support to drivers while driving: informing, advising/warning, intervening, and controlling/automated (SWOV, 2007). We prefer these levels of support for our category of ADAS, because of the granularity within the assisted category (informing, advising/warning, intervening). Examples of an informing ADAS are navigation systems and traffic congestion information systems. Examples of advising/warning ADAS are ISA and the advisory system discussed in this thesis. An example of intervening ADAS is ISA equipped with intervention technology on the throttle pedal.

1.3. Research Questions

For cooperative driving, the proposed nomadic advisory system computes appropriate acceleration/speed/distance values of a vehicle and advises drivers about how much they need to adjust their acceleration/speed/distance. In order to make sure that people will use the system, we need to find a way to adapt the driver's behavior from the present day driving mode to the future driving mode consisting of platoons with varying speed limits. In this thesis we focus on speed-related behavior.

In this thesis, we discuss two main research questions:

1. How should user interfaces inform drivers about recommended speed-related behavior in order to be alerting but not distracting? (Interaction Design)
 - What is the format of an effective speed-related advice (What, When, and How of speed advice)?
 - What is the optimal combination of modalities for the user interface of the system?
 - What is the relevant content for the speed advice?

2. How do we maximize the compliance of drivers with the system, such that drivers adopt a new behavior in order to participate in cooperative driving? (Persuasion Design)
 - How do we identify the most appropriate persuasion strategy in order to change driver's behavior toward cooperative driving behavior?
 - How do we evaluate the behavior change support system, using the most appropriate persuasion strategy?

1.4. Scope

1.4.1. User Interfaces for ADAS

In addressing the modality of user interfaces to be used in an ADAS, we rely on a system oriented definition (Nigay & Coutaz, 1993). In other words, we look at the modality of displaying information by the system to the users. The traditional modalities considered in cognitive science are related to the five human senses: visual, auditory, tactile (touch), olfactory (smell), and gustatory (taste). An extension of the tactile modality is the haptic modality, which gives kinesthetic or force feedback to the human's tactile sensory receptor. The haptic modality has been studied for user interfaces of ADAS (Mulder, Abbink, van Paassen, & Mulder, 2011).

Apart from using one single modality or unimodality, the use of multimodality has also been addressed in cognitive science and human computer interaction studies. Multimodality may increase the bandwidth of information transfer (Reeves, Lai, & Larson, 2004). In this context, the most employed modalities are visual, auditory, and tactile (Sarter, 2006). Moreover, using multiple channels to display information to users may decrease mental workload (Wickens, 2008).

Advanced driving assistance systems with an informing function usually employ visual and auditory modalities, such as in navigation systems. For intervening functions, ADAS may rely on the haptic modality, such as the haptic pedal as in a study on ISA (Adell, Varhelyi, & Hjalmdahl, 2008). In that study, the haptic pedal resisted the driver's foot movement so that the recommended speed was more likely to be complied with. For warning functions, there are numerous studies on the tactile modality (Spence & Ho, 2008), and some of them reported the advantage of the tactile modality over the visual (Scott & Gray, 2008) and the auditory (Mohebbi, Gray, & Tan, 2009) modalities. Moreover, studies on using the tactile modality have also been conducted for informing purpose (Boll, Asif, & Heuten, 2011; Cao, van der Sluis, Theune, op den Akker, & Nijholt, 2010).

Haptic and tactile modalities are not easy to implement in a portable or nomadic system. However, portable systems these days can be accompanied by extra buttons

to be attached in parts of the vehicle, such as the steering wheel (common products existing in the market). It should be easy to attach a small tactile interface on steering wheels, but this possibility is still limited by the vehicle manufacturers. If we aim for software based systems that are easily deployable in other nomadic devices, we are only left with the visual and auditory modalities. Therefore, we focus our study on the visual and auditory modalities for the user interface, and we would like to investigate a multimodal system in which the visual and auditory modalities are combined.

1.4.2. Persuasion

Persuasion is a way of influencing people's attitude and behavior through communication instead of through coercion. Persuasive technology is any interactive computing system designed to change a user's attitude and/or behavior through persuasion (Fogg, 2002). The notion of persuasive technology to be used in in-vehicle systems is not new. The speedometer is an example of a persuasive technology. Drivers change their speed according to the information of the speedometer, or in other words the speedometer influences the behavior of the drivers. The study of computers as persuasive technologies was introduced in 1997 (Fogg, 1998) followed by the proposal of a functional triad: computers as tools, computers as media, and computers as social actors (Fogg, 2002). According to this functional triad, the speedometer acts as a tool for drivers to support their behavior change.

The notion of persuasive technology in the driving context has been demonstrated by Jonsson, Zajicek, Harris, & Nass (2005) where drivers felt more comfortable receiving speech-based information delivered by a young person's voice compared to that of an old person's voice. The speech-based information allowed drivers to feel confident driving at a higher speed without worrying about exceeding the speed limit. This example shows that the use of appropriate user interface elements can be persuading drivers to change their behavior.

In addition to using user interface elements, the Belonitor project (Mazureck & Hattem, 2006) used in-vehicle technology to deliver persuasive messages. The persuasive messages informed about material rewards (points exchangeable with presents) acquired upon complying with a certain advice. The rewards were only effective during the test, and only 17% (speed keeping) and 19% (headway keeping) of the participants persisted in the advised behavior after the test. Similarly, a study using monetary rewards (Merrikhpour, Donmez, & Battista, 2012) reported that speed compliance dropped after the removal of monetary rewards. Therefore, we are interested in non-material rewards as a persuasion means to change driver's behavior.

1.5. Approach

In order to answer the Interaction Design questions, first of all we conducted an exploratory study. This study explored: 1) The What, When, and How of speed advice; 2) The visual and auditory user interfaces for a nomadic ADAS. The results of the exploratory study were used to establish: 1) The format of the speed advice; 2) The recommendations for improving the user interfaces. The design of the user interfaces was improved iteratively, therefore a follow up study was expected. Regarding the contents of the advice, it was found that acceleration messages were exchanged between vehicles using C-ACC technology. Therefore, we conducted a study for comparing speed advice and acceleration advice in order to find which message is more appropriate for drivers.

After answering all the Interaction Design questions, we outlined a proposal for the new system: Cooperative Speed Assistance (CSA). The final prototype consisted of CSA combined with a Portable Navigation System (PND). This final prototype was used as the behavior change support system in the persuasion experiment.

In order to answer the Persuasion Design questions, first of all we studied the persuasion literature and evaluated several persuasion concepts. The results were used to establish the persuasion concept, where the notion of a persuasion profile is used. A persuasion profile identifies a driver's susceptibility toward different persuasion strategies, which is different across drivers. Inspired by the literature on differences among drivers in speed related behavior, we developed a questionnaire. The questionnaire was distributed to a large number of drivers for the purpose of identifying individual differences in terms of personal values. The questionnaire was used to select participants for the persuasion experiment. This experiment was conducted in order to evaluate CSA as a behavior change support system. In the evaluation, the personal values were used as a point of departure for the choice of persuasion strategies.

A summary of the approach is illustrated in the following figure.

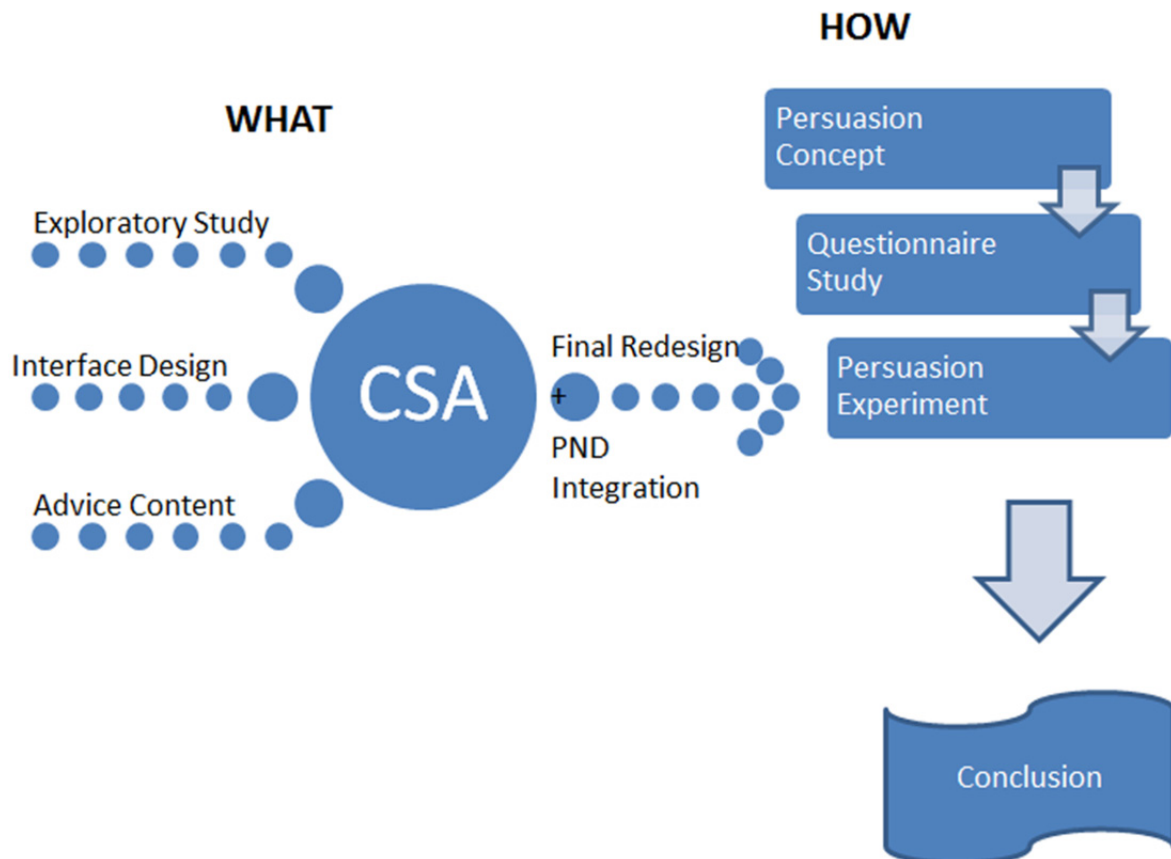


Figure 1.2. The approach to answering the research questions

In order to evaluate user interfaces for the driving context, it is important that we use a driving test. In the case of evaluating an ADAS, a suitable driving test is the one where drivers interact with the ADAS while actually driving. Real driving tasks can be performed in a vehicle simulator. This test is called Simulator Test. This kind of test is suitable for assessing multitasking ability (Burnett, 2009), which is widely used in attention and distraction related studies (Bach & Jæger, 2008).

Real driving tasks can also be performed in a real vehicle with the relevant equipment, called Road Test. For testing cooperative driving behavior, more than one vehicle is needed in order to have the coordination between vehicles. To measure the interaction between vehicles and infrastructure, a Field Operational Test (FOT) is conducted with multiple vehicles on the road with possibly equipped infrastructure (FOT-Net, 2010). FOTs have been conducted by the projects mentioned in Section 1.2.1.

While a FOT is usually triggered by the need for testing the technology, a Naturalistic Driving Study (NDS) is aimed at studying the driver's behavior. An NDS is conducted in everyday driving or naturalistic driving conditions. People can follow their natural driving pattern, because the data collection is conducted in a

discreet manner that does not show to the drivers (FOT-Net, 2010). In order to test cooperative driving with an NDS, the infrastructure should be ready and the existence of non-equipped vehicles on the road should be considered.

The Connect & Drive project did not conduct a FOT (V2V and V2I), instead only the V2V system was demonstrated in a road test (Ploeg et al., 2011). Because we are interested in how drivers interact with the user interface as well as how drivers change their behavior, it would be ideal to do an FOT combined with NDS. However, without an equipped infrastructure it is useless to conduct an NDS. Therefore, the limitation of this study is to conduct driving tests only by using a vehicle simulator.

Evaluating user interfaces for an in-vehicle system using driving simulators has its advantages over road tests: better control over experiment variables, having a safe environment, and cost effective, but it is limited in terms of the validity of the driver behavior (Burnett, 2009). There are several validity levels in measuring a driving experience: physical and behavior validity, where behavior validity can be determined in absolute and relative validity (Blaauw, 1982). Physical validity takes into account the accurate correspondence of the components of a simulator with a real vehicle, such as screen sizes and dynamics. Behavioral validity takes into account the extent to which drivers behave the same in the simulator compared to the real world. Absolute validity is if the numerical values between the simulator and real vehicle are the same. Relative validity is if the numerical values between the two systems are not the same, but the magnitude and direction are comparable. These measures of validity depend on the tasks measured.

A study by Wang et al. (2010) reported that a medium fidelity driving simulation is valid for measuring visual attention and task engagement. Based on their description, the simulator used by Wang et al. is similar to the simulator (Greendino, 2009, 2010, 2011) used in the four driving tests (Chapters 2,3,4,8) conducted for this thesis. The similarities are: complete real vehicle input devices such as steering wheel, brake and acceleration pedals, and speedometer; feedback through visual and auditory channels that varies with acceleration, braking, and movement on the road; and force feedback from the steering wheel. Therefore, we can use a fixed-base driving simulator for evaluating user interfaces in terms of cognitive ability and behavior on the task engagement level. Moreover, several studies (Godley, Triggs, & Fildes, 2002; Wang et al., 2010) reported the irrelevance of the degree of the fidelity of the simulator with the driving behavior. Therefore, we can use a medium-fidelity driving simulator for evaluating driver behavior with a relative validity.

1.6. Thesis Outline

This thesis consists of two parts. The first part (Chapters 2, 3, 4) presents studies on the user interface for CSA. The second part (Chapters 6, 7, 8) presents studies about a persuasion concept for increasing driver's compliance with cooperative driving behavior.

Chapter 2 describes the exploratory study for establishing the format of the speed advice and the recommendations for improving the user interface. It was found that the use of a peripheral visual interface is not distracting, and the auditory interface needed a redesign. Chapter 3 describes the redesign of the auditory interface. Chapter 4 describes a study on the comparison between speed advice and acceleration advice. The study compared acceleration advice with the speed advice used in Chapters 2 and 3. Chapter 5 summarizes the results of Chapters 2, 3, 4 and describes the final prototype of CSA.

Chapter 6 describes the persuasion concept and summarizes the literature about the identification of differences among drivers in speed related behavior. Chapter 7 describes the construction of the Personal Driving Value Questionnaire (PDV-Q) for the purpose of identifying differences among drivers in terms of personal values. Chapter 8 describes the evaluation of CSA as a behavior change support system. In order to allow an extended use of CSA in a driving simulator, a multi-level serious game experiment was set up for evaluating the behavior change while using CSA. Chapter 9 concludes the work in this thesis by outlining the contributions, reflections, and avenue for future studies.

2

Exploratory Study

This exploratory study is the first iteration in designing the user interface for Cooperative Speed Assistance (CSA), to identify issues for further exploration in later chapters. This study started with a focus on recommended speed as guidance for cooperative driving. The goal of the study is to answer the preliminary questions of What, When, and How of speed advice. The requirements for this study were inspired by focus groups (of 10 and 11 participants), existing advisory in-vehicle systems, and the project's use cases. The focus groups explored the information presentation modalities expected from a portable in-vehicle system, what participants thought about advisory and automated forms of cooperative driving, and the types of information that they expected from an advisory system. The requirements led to an exploration of information categories as well as visual and auditory interfaces for Cooperative Speed Assistance (CSA). The concept of distinguishable states of information and several visual and auditory design iterations resulted in two prototypes. The prototypes both provided users with speed recommendations in three states (Too Slow, Appropriate, Too Fast). In the Guidance prototype, users were only presented with colors, numbers, and sounds. In the Explanation prototype, in addition to colors, numbers, and sounds, users were also presented with icons and they could interact with buttons for more information. A driving simulator test was conducted in order to find users' preference for the prototypes and get insights for further developing advisory forms of cooperative driving assistance.²

² This chapter is based on:

Shahab, Q., Terken, J. (2009). *Advisory Cruise Control Device for an Intelligent Vehicle-Highway System*. Adjunct Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Essen, Germany.

Shahab, Q. (2009). *Design and Evaluation of a Cooperative Cruise Control Device for an Intelligent Vehicle-Highway System*. Eindverslagen Stan Ackermans Instituut 2009/042. Available from the Eindhoven University of Technology Library (ISBN: 978-90-444-0885-0).

2.1. Introduction

In cooperative driving, vehicles communicate their speed/acceleration/distance with each other, receive dynamic speed limits from the highway infrastructure, and send their own speed/acceleration/distance to the highway infrastructure. A cruise control that adapts a vehicle's speed to its preceding vehicle is already available in the current market, called Adaptive Cruise Control (ACC). ACC utilizes a sensor that detects the preceding vehicle in order to maintain a fixed distance, allowing a speed-varying cruise control (in contrast to the first generation of cruise control with fixed speed independent of distance). The next generation of cruise control is called Cooperative Adaptive Cruise Control (C-ACC). C-ACC utilizes wireless communication allowing speed adaptation with other vehicles and communication with the infrastructure.

It takes time for the C-ACC technology (automated system) to mature and be implemented by current vehicle manufacturers. An intermediate solution for cooperative driving is by including drivers in the loop (advisory system) instead of relying on cruise control technology, with a portable format for easy retrofit to current vehicles. For developing the advisory solution, we considered the difference between an advisory system and an automated system like ACC and C-ACC. The difference lies in what information is available to drivers and how drivers manipulate the speed of the vehicle. This difference triggered three questions to be answered by this exploratory study on an advisory system for cooperative driving: What information should be communicated to the drivers? When does the system communicate with the drivers? And how does the system communicate with the drivers?

With respect to the question of what information should be presented to the drivers, we narrowed down the scope of our research. While using ACC or C-ACC, drivers only have to set the desired fixed distance to the preceding car, which is called time gap. In road safety practice, the recommended time gap is two seconds (SWOV, 2010). In this case, the distance between two vehicles can be set independent of their speeds. In an advisory system, although recommended time gap is communicated, drivers still have to adjust the vehicle's speed by themselves. Moreover, only the speed information is commonly available through the vehicle's speedometer, which in turn provides feedback to the human controller for easy speed manipulation. Based on this consideration, we would like to support drivers in speed control, and we decided that speed should be communicated to drivers as the main guidance means. The proposed advisory system is called Cooperative Speed Assistance (CSA). In addition, with respect to the question of what information should be presented to the drivers, this exploratory study also address the questions of what kind of additional information people would like to be informed about.

When should the system present information to drivers? As introduced in Chapter 1, cooperative driving aims for uniform speed among a platoon of vehicles. This is enabled by communication between vehicles (V2V) and between vehicles and infrastructure (V2I) and requires constant adaptation to the traffic condition. This constant adaptation may trigger a situation where speed information needs to be updated to drivers as often as possible. However, we do not want to have a system that provides drivers with new information too often, as to avoid the system being judged as intrusive. In this exploratory study, we addressed this question: How often should the information be updated by the system?

How should the system present information to drivers? In this exploratory study, we tried to find the appropriate multimodal user interfaces for an effective speed advice. The specific question is whether the multimodal information presentation is useful and actually triggers the drivers to comply with the speed advice.

This chapter describes the process toward the first prototype of the CSA system. Section 2.2 describes a requirements gathering study to answer the What-When-How questions through conducting focus groups, exploring existing products, and considering use cases. Section 2.3 describes the development of a preliminary speed advice concept and a multimodal user interface toward the first prototypes of the CSA system. Section 2.4 presents an initial evaluation of the speed advice concept using a driving simulator test. At the end of this chapter, results from the driving simulator test are discussed and insights on how to proceed further in designing the CSA system are formulated.

2.2. Requirements

2.2.1. User Requirements

Approach

In order to establish user requirements for an interactive system, focus groups were conducted. The focus groups are one of several ways to uncover the needs, expectations, and aspirations of users, in which a requirement set is iteratively discussed, clarified, refined, and possibly re-scoped (Rogers, Sharp, & Preece, 2007).

After conducting several informal interviews with ordinary drivers, we obtained a set of materials to be discussed in a focus group. In a focus group, participants discuss various issues, arguing with each other and trying to reach a consensus. However, this focus group style was slightly modified by combining it with a brainstorm, which means that in the end the participants did not necessarily have to reach a consensus. This way, apart from understanding user's needs, expectations, and aspirations, the discussion can also give useful inputs to the concept development of an envisioned system.

Participants were selected from employees of the university having a driver's license and having actually driven for at least 1.5 years. They normally drove passenger cars. As there are two different solutions for cooperative driving systems (automated and advisory), both of the solutions were addressed in the focus group discussions. Concerns about safety and comfort were also addressed in the discussions. Safety issues are related to trust (Lee & See, 2004), so trust was addressed explicitly. Comfort relates to usefulness and annoyance issues of the system, which were also addressed in the focus group.

The material for the discussions started from familiar Advanced Driver Assistance System (ADAS) devices such as Portable Navigation Devices (PND) and basic cruise control systems, because they are widely available in passenger cars these days. The goal of providing this discussion topic is to sensitize the participants to the topics in the later stages of the focus group. This was followed by a presentation about ACC, since knowledge on ACC was not expected. Then, the facilitator explained the idea of a C-ACC system by showing a scenario with a simple animation (see Appendix A.1, Figure A.1). From each of the ACC and C-ACC presentations, a discussion followed. Advisory systems and different Human-Machine Interface systems were also discussed afterwards. Participants were asked to freely share their expectations of the systems in the focus group.

The requirements were gathered from two focus-group/brainstorm discussions conducted with international employees of the Industrial Design department. In each group, the participants knew each other (coworkers). The first group (FG1) consisted of 10 people (7 female, 3 male, age 23-28). They came from Belgium (1), Brazil (1), Canada (1), China (1), Chile (1), Italy (2), Netherlands (2), and Spain (1). The second group (FG2) consisted of 11 people (4 female, 7 male, age 23-31). They came from Belgium (2), Brazil (1), China (1), Netherlands (5), and USA (2). These groups are mutually exclusive.

Results

The details of the focus group/brainstorm structure can be found in Appendix A.1. The summary of the discussions is as follows:

1. **Advanced Driver Assistance System (ADAS):** Participants expected an ADAS to inform them about traffic jams, unavailable roads, traffic density, and environmental conditions such as speed limit, safety level, and traffic regulations. They would love to see good visualizations to present such rich information. In case of feedbacks, their preference in order of importance is haptics then non-speech sound then speech then visual. They would like to receive visual information the least, because driving was considered already visually demanding. They strongly disliked intrusive auditory feedback, e.g. PND with

too frequent speech commands. Unlike the example of the common PND, they wanted to control the system easily, even while driving. This was followed by a dislike of touch screens.

2. **Cruise Control (CC):** Participants of FG1 liked CC because of the fixed speed and the ability to change speeds at their wish. The fact that CC turns off when the brake pedal is depressed was also considered a good feature of CC. Only one participant of FG2 did not like CC, because it was considered sleep inducing. All other participants liked CC for keeping their cars within speed limit.
3. **Adaptive Cruise Control (ACC):** Participants of FG1 did not like ACC because if there is a very slow car in front of them, they want to speed up on the current lane before changing lanes to overtake. Participants of FG2 liked the idea of ACC, but they worried about the cars behind them. They worried that the automatic deceleration would not send any signals to following cars like the way brake lights do.
4. **Cooperative Adaptive Cruise Control (C-ACC):** Participants of FG1 liked the idea of C-ACC more than ACC, because C-ACC promises a more appropriate speed adaptation. ACC was considered harshly adapting speeds to only immediate vehicles, and C-ACC was considered smarter in adaptation, especially relevant to traffic jam prevention. However, they still did not like the idea of the car taking control. Participants of FG2 also did not like the car to be completely taking over control of the pedal operation. To participants of FG1, an added value of C-ACC was the possibility to acquire other information such as information about traffic jams. Participants of FG2 liked the idea of saving time by avoiding traffic jams using a C-ACC system. They suggested the system to have time-to-destination calculation related to the speed taken. In addition, they would like to have the system combined with a PND, so it can also suggest alternative routes when there is an instable traffic flow. This way, the system would really convince them of its value. In order to trust/believe that the system is really useful, they would have to try the system and experience the benefits first. They believed that everybody should use the system before there would be any positive effects on the traffic flow.
5. **Cooperative Speed Assistance (CSA):** During the discussion of FG1, the word “suggestion system” was mentioned, so when presented with CSA, participants liked it. They liked the idea of extra information, and always wanted to remain the decision taker upon the information. In addition, they only wanted to be advised if consequences of the action taken upon following the advice would be communicated. The words “options” and “recommendations” were mentioned in FG2, before they were presented with CSA. Therefore, they also preferred CSA to

C-ACC. Participants of FG1 liked haptic pedal feedback compared to speech advice. However, participants of FG2 did not like haptic pedal, as it is not the natural way of interacting with existing cars. Instead, they preferred auditory feedback (sound signals over speech advice). The discussion about CSA was not limited to portable devices. Participants freely talked about advisory cooperative driving systems, both portable and in-car systems.

Some results of the focus groups confirmed the results from a survey by van Driel & van Arem (2005) on Advanced Driver Assistance System (ADAS). They found that more than 42% of the respondents liked to be supported during congestion driving in highways, and more than 90% of the respondents wanted to be warned for upcoming traffic conditions e.g. congestion and road works.

Requirements

In conclusion, the user requirements for CSA were:

- The system should be advisory, not automated
- The system should provide information about the reasons behind the speed advice and its consequences (results of following the advice)
- Auditory feedback such as sound signals is acceptable, but speech should be minimal

2.2.2. Information Presentation Requirements

Approach

The information presented by an advisory system should be highly salient in order for the advice to be followed as soon as possible. The high salience means that the different types of information should be organized appropriately and should be easily distinguishable by a human user while driving. We explored best practices in ADAS design followed by an analysis derived from the literature.

Results

We found that information should be presented in big chunks that are easily distinguishable from each other. Using different states is useful for conveying information about how the driver's current speed differs from the recommended speed, e.g. too fast or too slow. A notable example of advisory ADAS is the MobilEye system (MobilEye, 2008-2012), especially the headway monitoring system. The system employs three states of safety: red, amber, and green. These color states are popular as known in traffic lights. However, using green-amber-red color codes for safety is regarded not color-blind friendly, as the most common color-blind type is red-green. Taking into account that the number of color-blind people is only 8.5% of male and 0.5% of female (Kalloniatis & Luu, 1995), it is still appropriate to use color codes for distinguishing safety levels. In order to decide which colors are safe (easily

distinguishable from each other), a color contrast analysis can be performed beforehand.

Overall, the usage of three colors in MobilEye and traffic lights inspired a design requirement of using not too many colors representing the states of current speed vs. recommended speed. The use of colors led to a consideration for visual feedback although the focus groups did not prioritize it. Another reason to pursue the use of visual feedback is to prevent the CSA device from generating too many sound signals for conveying information related to different states.

The reason for the low preference for visual feedback by the focus groups is the fact that driving is a visually demanding activity. While driving, a driver may use glances to switch between looking at the road and looking at an in-vehicle visual display. Therefore, the time used to glance at the display should be minimized, by adding glanceable display elements. A glanceable display is a visual display that enables a user to obtain visual information as quickly as possible with low cognitive effort. According to Matthews (2007), a user can obtain visual information from a secondary task in very short glances while focusing on the main task. As a result, a glanceable display can increase multitasking ability. The presentation of information through the glanceable display needs to be determined during the design process. For example, colors, as discussed in the previous paragraph can be easily glanceable if the colored display elements are large enough and the spatial location of the display is appropriate to the driver's eyes.

Requirements

Regarding information presentation, the requirements were as follows:

- The information about current speed and recommended speed should be distinguishable into different states
- The visual display should be glanceable, using a minimal set of different colors

2.2.3. Project Requirements

The CSA system should support at least one of the use cases from the Connect & Drive Project (2008). These use cases are also useful for defining scenarios in which users can drive while using the device. In the project, three use cases were designated to be supported by the system's functionalities. The use cases are:

1. Platooning at an increasing size (Figure 2.1), i.e. when one or more vehicles are joining the platoon, e.g. at junctions and narrowing roads. This also includes vehicles cutting into the driver's lane.

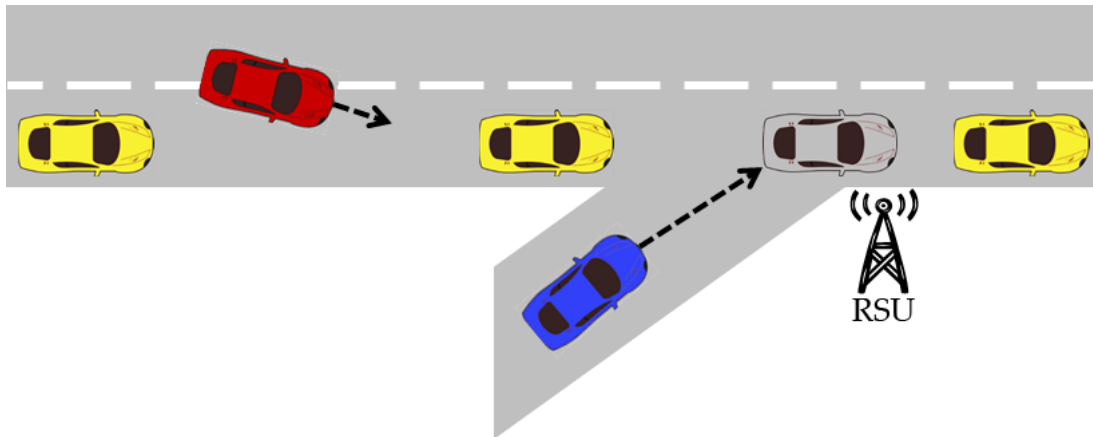


Figure 2.1. Scenario of platooning at increasing size (Connect & Drive Project, 2008), with yellow cars indicating a platoon of vehicles. The blue car is joining the platoon (toward the position of the transparent car) at a junction. The red car is joining the platoon by cutting into the platoon's lane.

2. Platooning at a decreasing size (Figure 2.2), i.e. when one or more vehicles are leaving the platoon, e.g. at splits and widening roads. This also includes vehicles cutting out of the driver's lane.

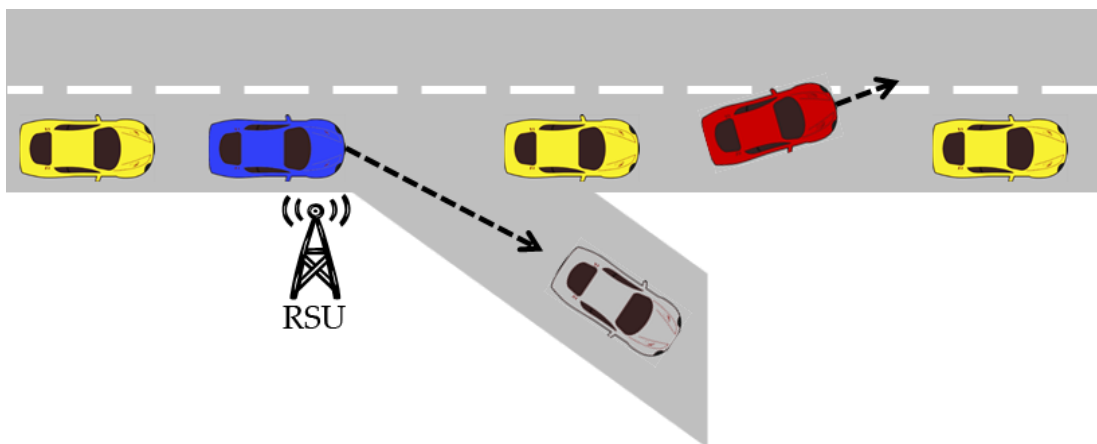


Figure 2.2. Scenario of platooning at decreasing size (Connect & Drive Project, 2008), with yellow cars indicating a platoon of vehicles. The blue car is leaving the platoon (toward the position of the transparent car) at a road split. The red car is leaving the platoon by cutting out of the platoon's lane.

3. Platooning at a constant size, i.e. when there is neither increase nor decrease of platoon size, but general disturbances such as sudden brake and incidents. This includes any traffic obstructions.

The user requirements and the information presentation requirements were used to develop the speed advice concept using different states and other information. The development of the concept and the development of the prototype using the project use cases are presented in the next section (Section 2.3.1). The design of the visual display (information presentation requirement) and the design of the auditory display (user requirement) follow in Section 2.3.2 and Section 2.3.3 respectively.

2.3. Concept and Design

2.3.1. Concept Development

According to the information presentation requirements, the system should give speed advice to the driver in distinguishable states. In addition, according to the user requirements the reasons behind the speed advice and its consequences should be provided.

This section discusses first the possible (different) states in which drivers might receive feedback from the system and outlines the reasoning on deciding which states are important. The distinguishable states refer to the conditions about the vehicle's speed with respect to whether the driver needs to take or not to take any actions for a stable traffic.

The distinguishable states can be arranged through the following possible combinations:

- Two states: safe and unsafe
- Three states: safe, caution, unsafe
- Three states: disturbing, safe, unsafe
- Four states: disturbing, safe, caution, unsafe

where safe means that the speed is within the safe limit for a stable traffic; unsafe is the opposite; caution is a transition from safe to unsafe; and disturbing is still safe, but the speed is too slow thus causing disturbance to the traffic.

Among the four possibilities of number of states, the {safe, unsafe} option was dropped, because it does not advise users about the third state (disturbing). Therefore, the {safe, caution, unsafe} option was also dropped for the same reason. The {disturbing, safe, caution, safe} option was also dropped, because caution is only a transitional state between safe and unsafe. Therefore, only one possibility was picked from this category i.e. the one providing three states {disturbing, safe, unsafe}. In order to make more sense and to relate more directly to speed, it was decided to call this series of states {Too Slow, Appropriate, Too Fast} for the rest of this thesis.

In order to test whether the reasons behind the speed advice and its consequences are indeed useful, we addressed the possible (different) levels (depth) of information:

- a. One level: for example, advisory feedbacks about speed states e.g. too fast/too slow, using colors and numbers for guidance like in MobilEye (MobilEye, 2008-2012).
- b. Multiple levels: for example, advisory feedbacks, plus symbols or texts for explanation why an advice is presented, and speech for providing the consequence of the action following the advice.

We decided to create two concepts, one with a single level of information (as in (a) above), and one with multiple levels of information (as in (b) above). In order to implement the two concepts, we reviewed the information associated with each state, with examples outlined in Table 2.1. The information was then categorized into four types: 1) information from the vehicle (the speed advice); 2) information from the environment (the reason behind the speed advice); 3) further explanation on information from the environment (the reason behind the speed advice); and 4) consequences of actions after following an advice. The first concept, called the Guidance concept, only communicates the first type of information (about the vehicle). The second concept, called the Explanation concept, communicates all types of information.

Table 2.1: Types of information from the CSA concepts

From both concepts	From Explanation concept
1) Vehicle (Visual and Sound) <ul style="list-style-type: none"> • Speed is within limit (Appropriate) • Speed is below limit (Too Slow) • Speed is over limit (Too Fast) 	2) Environment (Visual) <ul style="list-style-type: none"> • Traffic Jam Ahead • Warning (general disturbances) • Merging in Front • Merging Behind
	3) Explanation (Visual) <ul style="list-style-type: none"> • X km ahead, at Street Name, X m length • Exceeding speed limit! • X km ahead, X vehicles, X km/h average speed
	4) Consequences (Speech) <ul style="list-style-type: none"> • You will be X minutes faster through the traffic jam • You will be safer! • You will help X cars ahead • You will help X cars behind you

Information from the environment was inferred from the use cases of the project as described in Section 2.2.3. For this first prototyping iteration, two use cases were used: platooning at an increasing size and platooning at a constant size. Platooning at increasing size happens when other vehicles are cutting into the driver's lane, and this can happen either in front of the driver or behind the driver. The case where vehicles are cutting somewhere ahead of the driver is called Merging in Front. The case where vehicles are cutting somewhere behind the driver is called Merging Behind. Platooning at constant size may still allow drivers to experience disturbance caused by slow or blocked traffic, thus general road disturbances (like road construction and slippery road) as in Table 2.1 were anticipated.

Explanations were taken from existing traffic information (electronic traffic signs for queue/congestion), while Consequences were only guessed. When implemented in real life, more information needs to be extracted from the engineers of the project (Connect & Drive Project, 2008), in order to obtain the actual consequences that can

be transmitted to the vehicles in the cooperative driving system and then communicated to the drivers.

The two concepts were designed to be tested through working prototypes. The two prototypes both informed users about their speed choice in three states (Too Slow, Appropriate, Too Fast), but the Guidance prototype had only one level of information, whereas the Explanation prototype had multiple levels. In other words, the Guidance prototype communicates the speed advice only, and the Explanation prototype communicates the reasons and the consequences. An example scenario of how the two prototypes differed is described in Table 2.2.

Table 2.2: Comparison between Guidance prototype and Explanation prototypes through an example scenario

Guidance Prototype	Explanation Prototype
ADVICE: You are driving too fast (speed over limit) and need to slow down.	REASON: You are driving too fast (speed over limit) and need to slow down, because there is a traffic jam ahead.
	REASON: More information indicates that the traffic jam is on the Marconilaan 2 km ahead, with a length of 500 m.
	CONSEQUENCE: If you follow the advice, you will arrive at the traffic jam when it dissolves and you will save 15 minutes of your time.

2.3.2. Visual Interface Design

The visual interface is needed for two purposes: glanceable display and information visualization. For a glanceable display, it is important to show color/brightness changes on a large part of the screen. For information visualization, there are three types of information: the speed advice, information from the environment, and explanation of the speed advice (see Table 2.1).

There were several design iterations toward deciding the visualization of the speed advice in accordance to the three basic states. The three states imply that the visual interface is dynamic, changing according to the information from the vehicle and the environment. The requirements for the changing (dynamic) screen elements are:

1. It has to be easily glanceable. Therefore, the size of the visual elements should be large. The color coded visual elements should have different luminosity contrast, which in turn should also be color-blind friendly.

2. As a cooperative driving state can change within seconds, the screen elements should not change format during the display period. In other words, it should not be animated and it should not blink.
3. Visual elements should be easily understandable, without users having to be pre-informed that there are three states possible.

Informal color coding tests with three designers were conducted until we obtained white for Too Slow, black for Appropriate, and red for Too Fast (See Appendix A.2 for color contrast analysis). Informal glanceable display tests with two designers were conducted, resulting in a decision of not to use a large icon, but to use the whole background to display the different colors. The design of the speed advice was iteratively explored in order not to create a cluttered display. Finally, the visual interface of the speed advice is as in Figure 2.3.

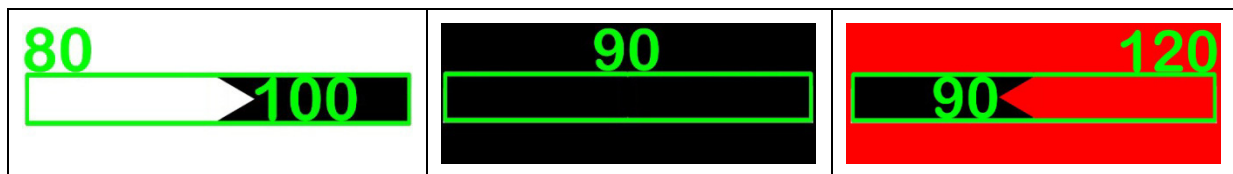


Figure 2.3. Final graphical information of states. Left: Too Slow, 80 km/h current speed with a 100 km/h speed advice; Middle: Appropriate, 90 km/h current speed; Right: Too Fast, 120 km/h current speed with a 90 km/h speed advice.

Table 2.3: Icons used for information visualization

Environment	Icons	Text Explanation Example
Traffic Jam		5 km Marconilaan 500 m
Warning		3 km! 500 m
Merging in Front		3000 m 200 vehicles 90 km/h
Merging Behind		3000 m 200 vehicles 100 km/h

The icons in the Table 2.3 are used in the Explanation prototype, for visualizing information from the environment as the reason behind the speed advice. The icons were adapted from European traffic signs, except Merging In Front and Merging Behind, which were designed especially for this exploratory study. For the extra explanation, text of the same colors as the other text color on the screen is used.

2.3.3. Auditory Interface Design

For this exploratory study, the auditory interface was designed for conveying the three states as conveyed by the visual interface. In other words, the {Too Slow, Appropriate, Too Fast} information was presented redundantly, both with the visual modality and the auditory modality. In case the driver is not alerted by the visual interface, the auditory interface may alert the driver to glance at the screen as soon as the information is heard.

The auditory information was intended to prevent “auditory pollution”, therefore we decided to design for two conditions only. There were four possible transitions between the states of speed advice: from Appropriate to Too Slow, from Too Slow to Appropriate, from Appropriate to Too Fast, from Too Fast to Appropriate. The auditory interface was designed only for the transition leaving the Appropriate state (from Appropriate to Too Slow and from Appropriate to Too Fast), which are more urgent than the change toward Appropriate state. The change toward Too Slow state is an alert for entering the Too Slow condition, and similarly for Too Fast. Displaying one signal at the beginning of the state change is good enough for triggering glancing at the screen, because during the course of Too Slow and Too Fast states the screen continuously displays the appropriate color. Only one time signal is audible per state change.

A relevant study for designing sounds for Too Slow and Too Fast is the study on designing sounds for monitoring helicopter’s rotor underspeed and rotor overspeed (Edworthy, Hellier, & Hards, 1995). They used four acoustic parameters in the design process: Pitch, Speed (tempo), Inharmonicity, and Rhythm. In their first experiment, these four parameters of the sound signals were varied and participants were asked to associate the signals with given adjectives. They reported that an increase in pitch indicated rising, high, urgent, dangerous; a decrease in pitch indicated low, steady; an increase in tempo indicated urgent, fast, dangerous. In their second experiment, the different parameters were combined together in the construction of the sounds for monitoring the trend toward going too slow or too fast. They reported that increasing tempo indicated dangerous; both increasing pitch and increasing tempo conveyed the trend of increasing urgency; and rotor underspeed could be estimated by the sound that increased in tempo but decreased in pitch, as well as the one that increased in pitch but decreased in tempo, which had yet to be tested through a simulation test (inconclusive).

In this exploratory study, for designing the sound signals for Appropriate-to-Too Slow and Appropriate-to-Too Fast transitions only pitch and tempo were used. Rhythm was not used, because the signal for entering a new state is a single, non-repeating sound signal (very short duration) instead of a repeating (monitoring) sound. We decided not to apply inharmonicity in the sound design, because there was no access to partial frequencies for modification of inharmonicity in the pre-recorded sound samples we used.

Due to the limit of the duration (sounds should be as short as possible and not intrusive), only three subsequent tones were included in each sound signal. Each of these three tones had different duration and pitch properties, where varying the duration of the tones led to different tempo perception (ascending/descending) of the sound signals. The pitch properties (musical note symbols) were: B3 (249.15 Hz), C#4 (279.11 Hz), and G#4 (420 Hz), with amplitude envelope as shown in Figure 2.4. The duration properties were: base (164 ms), 150% faster (123 ms), and 200% faster (82 ms).

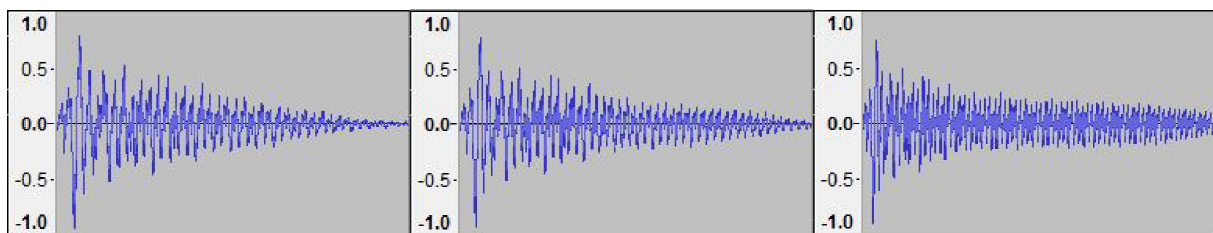


Figure 2.4. Amplitude envelopes for the three different pitch (B3, C#4, G#4). X-axes of the graph indicate time, all displaying 164 ms duration (the base duration).

By referring to the results from the above mentioned study (Edworthy, Hellier, & Hards, 1995), the following sounds were designed: 1) Ascending pitch, ascending tempo; 2) Descending pitch, ascending tempo; and 3) Ascending pitch, descending tempo. Descending pitch, descending tempo sound was not created, because according to the above study, the perception test on the combination of these parameters was not conclusive. Sound 1 was designed for indication of entering Too Slow state. Sound 2 and Sound 3 were designed for indication of entering Too Fast state, to find which sound is more appropriate. The properties of the sounds are listed in Table 2.4 and graphically illustrated in Figure 2.5.

Informal but in-depth discussions were arranged with two designers to elicit feedbacks on the three sound items. Both of them did not perceive the ascending pitch/tempo as an indication that the speed of the car is too fast or too slow, instead they perceived the sounds as an advice to speed up or slow down (see Table 2.4, last column). They did not perceive any danger/urgent indications from the sounds, so the sounds were considered as advices.

Then they were asked to comment on the three sound items in comparison: Sound 1 vs. Sound 2, Sound 1 vs. Sound 3. When asked about Sound 1 vs. Sound 2, they thought that Sound 1 is an advice to speed up, and Sound 2 is an advice to slow down. When asked about Sound 1 vs. Sound 3, they thought that Sound 3 can be an advice to slow down, due to its descending tempo. Therefore, ascending pitch with descending tempo can still mean that the car is too fast, although the descending tempo is still the factor perceived as an advice to slow down. The decision was then to use Sound 1 and Sound 2 for advices to speed up and slow down, respectively instead of indication of current states (condition of the vehicle). Because of this, we decided that the status information about the vehicle (warning/alarm) is provided only by the visual interface.

Table 2.4: Three sound signals designed for testing

Transitions	Sound signal	Properties			Perceived Meaning
		Tone 1	Tone 2	Tone 3	
Appropriate to Too Slow	1) Ascending pitch, ascending tempo	249.15 Hz 164 ms	279.11 Hz 123 ms	420 Hz 82 ms	Speed Up
Appropriate to Too Fast	2) Descending pitch, ascending tempo	420 Hz 164 ms	279.11 Hz 123 ms	249.15 Hz 82 ms	Slow Down
Appropriate to Too Fast	3) Ascending pitch, descending tempo	249.15 Hz 82 ms	279.11 Hz 123 ms	420 Hz 164 ms	Slow Down

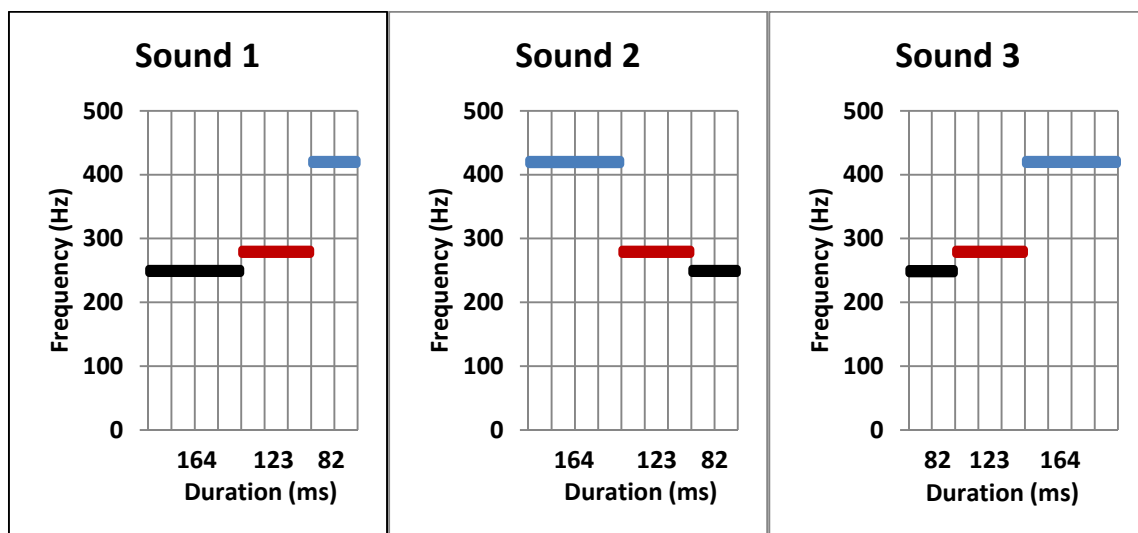


Figure 2.5. Graphical representation of the sounds. The black bar represents 249.15Hz signal, the red bar represents 279.11Hz signal, the blue bar represents 420Hz signal.

As outlined in Table 2.1, the auditory interface for the Explanation prototype also included speech feedback for the purpose of informing users about the consequence behind each speed advice. The speech feedback was designed using a Text-To-

Speech program (Acapela Group, 2009). The texts were taken from information states as in the table.

2.4. Driving Simulator Test

2.4.1. Preparation

Based on the concept development in the previous section, there were two prototypes to be tested: the Guidance prototype and the Explanation prototype. The general aim of this test was to answer the questions on what, when, and how to present speed advice from a CSA device. We tried to answer the questions by finding participants' subjective preferences for the two prototypes and the reasons behind the preferences.

The two prototypes were designed to inform users about speed choice in three states (Too Slow, Appropriate, Too Fast). The two prototypes shared the same feedback function (visual and auditory) to inform users, and one control function where users could give inputs to the device: the mute button to mute the auditory interface. The difference between the prototypes was in the visual interface. In the Guidance prototype, users were only presented with color codes and numbers. In the Explanation prototype, in addition to color codes and numbers, users were presented with icons and they could interact with buttons for more information (explanation/consequences). Thus the Explanation prototype had two more control functions: the text information button and the speech information button. The Guidance prototype is shown in Figure 2.6. The Explanation prototype is shown in Figure 2.7.

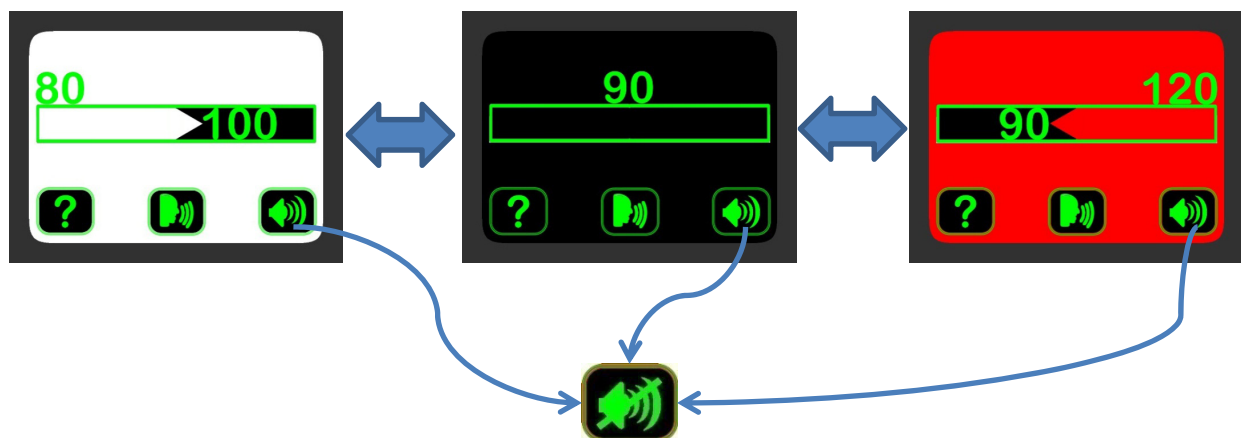


Figure 2.6. Guidance Prototype with three states. The screen colors change according to the state of the speed: white, black, red for Too Slow, Appropriate, Too Fast, respectively. Only one button is accessible: the mute button (to mute all sounds). See Figure 2.3 for the meaning of the numbers. When the screen changes to white, the Too Slow sound is played; and when the screen changes to red, the Too Fast sound is played.

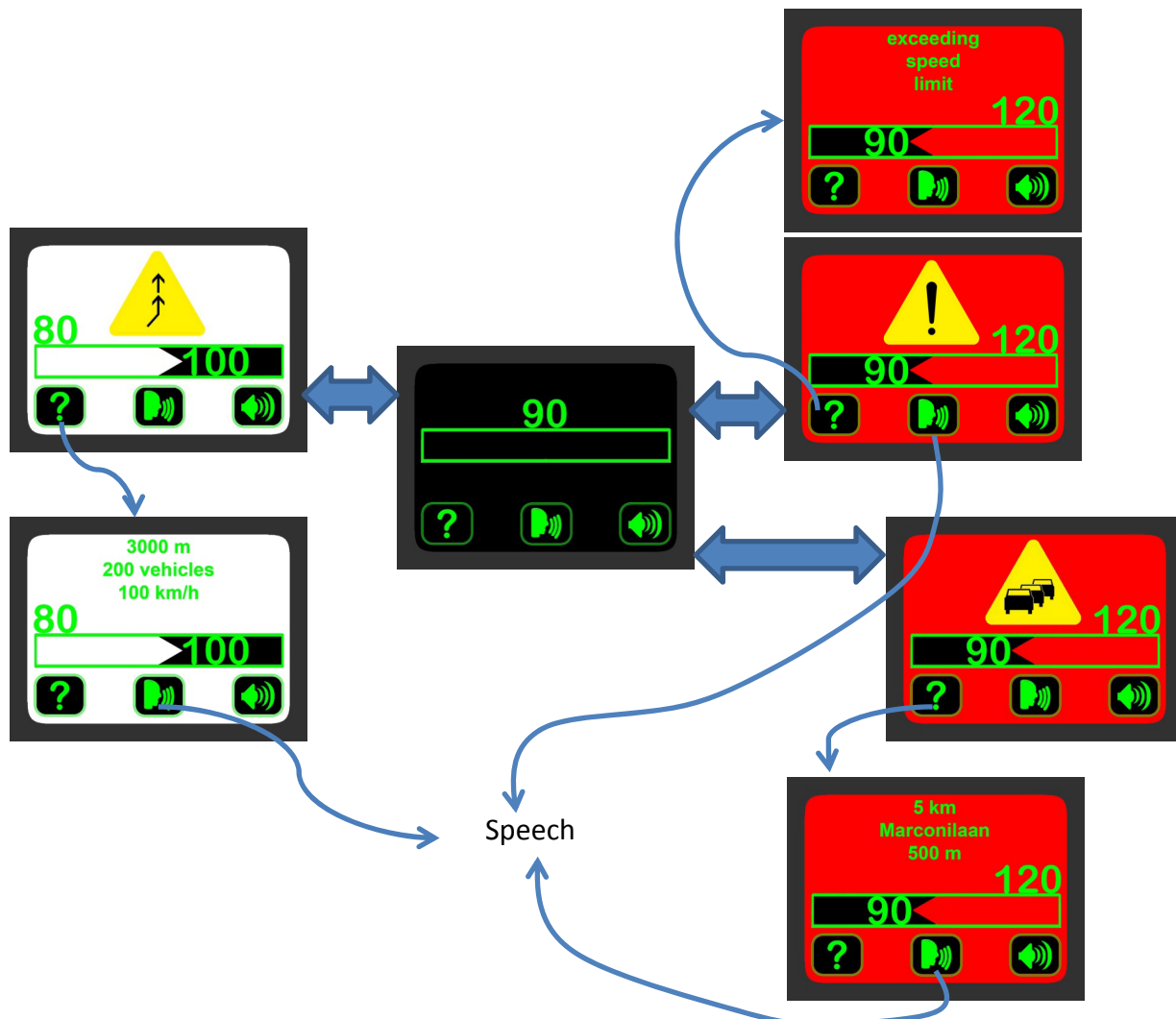


Figure 2.7. Explanation Prototype with three states: Too Slow (with Merge Behind icon), Appropriate, Too Fast (with Safety icon, or with Traffic Jam icon). Apart from the mute button, two other buttons are accessible: the '?' button leads to another screen with text explanation; the speech button leads to speech explanation as described in Table 2.1. When the screen changes to white, the Too Slow sound is played; and when the screen changes to red, the Too Fast sound is played.

The system was designed to repeat information after 2 seconds if the traffic condition is still the same, or to provide new information if there is a change in the traffic condition. Therefore, for this exploratory study the system displayed information from traffic every 2 seconds, both visually and auditorily. This time estimation was taken from the two second rule (SWOV, 2010), indicating that a driver needs 2 seconds to react to the situation and control the vehicle in the case of an emergency. This limit was taken as a preliminary time-out of information update for this exploratory study. As this limit depends on the context and on the driver's preference, it needs to be determined in future research.

Regarding the accuracy of the recommended speed, we made an ad-hoc estimation of 5 km/h intervals. This means that drivers would receive information about how

much to increase or decrease the speed in intervals of 5 km/h. This estimation was intended to provide a higher resolution than the 10 km/h marks available in existing speedometers with continuous (analog) scale.

The prototypes were developed using the Java programming language and were connected to a medium-fidelity fixed-base driving simulator (Greendino, 2009) through a local area network. The visual interface was displayed on a 7-inch touch screen (640x480 pixel size) that was attached to the left side of the simulator due to limited space. It was placed under the left mirror, so at least it is still glanceable when the driver looks at the mirror to see other cars on the left lane.

Figure 2.8 shows the driving simulator running a highway scenario, with the prototype attached under the left mirror. The prototype is showing that the user is too fast (red background), with 120 km/h as the user's current speed and 90 km/h as the recommended speed for that condition while also showing traffic jam icon, indicating a traffic jam ahead.



Figure 2.8. a) The driving simulator; b) The prototype attached to the driving simulator

2.4.2. Procedure

Twenty four participants were recruited for this test (8 female, 16 male, age 23-33). When asked about PND usage, 7 of them never used it (they did not like it nor have it), 9 used it a little bit (only to unknown places), 7 used it sometimes (mostly in the city), and only 1 used it most of the time. Half of the participants used the Guidance prototype first and then the Explanation prototype; half of the participants used the Explanation prototype first and then the Guidance prototype. Since there were 24 participants, there were 12 of them in each group.

Participants were asked to drive in the driving simulator for two time blocks of 5-10 minutes each. While driving, they were asked to explore the buttons as available in each prototype. Before using the Explanation prototype they were told to try all three available buttons, and before using the Guidance prototype they were told to use only the mute button.

A highway scenario with moderate traffic was executed within each time block for each prototype. The scenario consisted of Episode 1 (Disturbances), Episode 2 (Merging In Front), and Episode 3 (Merging Behind). For Episode 1, Traffic Jam and General Disturbance (Warning) conditions were used (see Table 2.1). Episode 2 is the Merging in Front condition where the participant had to slow down. Episode 3 is the Merging Behind condition where the participant had to speed up.

The episodes in the scenario were presented randomly. This was caused by the random behavior of the vehicle agents in the simulator, which in turn also influenced the length of the scenario. Within each time block, participants were required to interact sufficiently with the device (i.e. experiencing all episodes while interacting with the device).

Experiencing the device is assumed to have an effect on the user's understanding of the interface elements. Therefore, through a questionnaire participants were asked to rate: overall impression of each prototype; each visual element (color changes in both prototypes, buttons of Explanation prototype, icons of Explanation prototype); each of the two auditory feedbacks (Slow Down & Speed Up). The interface elements were rated using the following adjectives: useful, difficult to understand, important, and annoying, with a 5-point Likert scale of {'Not at all', 'Somewhat not', 'So-so', 'Somewhat yes', 'Definitely'}. The scale of annoyance was then inverted into pleasantness, in order to make high ratings express positive values.

The rest of the questionnaire was about subjective urgency perception and self-reported compliance with the device. Participants were asked to indicate whether using the prototypes they could map three different levels of urgency situations: low, medium, high, with a 5-point Likert scale of {'False', 'Somewhat false', 'Undecided', 'Somewhat true', and 'True'}. The same rating was also asked for their tendency to take action upon color changes and hearing sounds. The questionnaires can be seen in Appendix A.3.

At the end of the test, participants were interviewed with reference to the following questions (unless the questions had been answered by their spontaneous verbalizations while driving and filling in the questionnaire): Which prototype do you prefer? Which one caused you to obey the advice more than the other? What (intrinsic) motivation caused you to obey it? Which scenarios are important for you to receive an advice for? Sensing urgencies? What other ways would you comply with the advice? What (extrinsic) means would you like to be motivated with? If explanation was needed, participants were asked specific questions regarding each questionnaire response.

2.4.3. Results – Quantitative

The first step of the data analysis focused on the explicitly indicated preferences of participants when asked during the interview. After getting the preferences of participants for both prototypes, analysis was done on each rating from participants regarding each prototype and each element in the prototypes. The purpose is to find whether there was a relation between participant's preference and the ratings.

First of all, Chi Square Test of Independence showed that the order of prototype usage during the test did not show any influence on participant's prototype preference ($\chi^2=.178$, $df=1$, $p=.68$). Therefore, for the further analysis of the data, the order of usage was not taken into account.

From the 24 participants, there were 15 participants who preferred the Explanation Prototype, and 9 participants who preferred the Guidance Prototype. A binomial test was performed on the choice between Guidance Prototype and Explanation Prototype. With a probability of 0.5 and 24 participants, the fact that Explanation Prototype was preferred by 15 people is not significant.

The prototype preference was compared with the overall ratings of each prototype, in order to find whether the choice of prototype is dependent on the higher rating or not. Some participants rated both prototypes equally, as seen in Table 2.5. The Chi Square Test of Independence showed a significant result for rejecting independence ($\chi^2=11.135$, $df=2$, $p<.001$). This indicates that the prototype claimed as the preferred prototype during the post-test interview was the prototype with the higher rating.

Table 2.5. Prototype with Higher Rating vs. Preference for Guidance (G) or Explanation (E) prototype

Rating	Preference		
	G	E	Total
Same	1	5	6
G is higher	8	3	11
E is higher	0	7	7
Total	9	15	24

To find whether there was a difference between those who preferred the Guidance Prototype and those who preferred the Explanation prototype with respect to ratings of colors and sounds, Mann-Whitney U tests were computed. The analysis was performed on the usefulness, understandability, importance, and pleasantness of colors (Figure 2.9) and sounds (Figure 2.10).

Figure 2.9 shows the usefulness, understandability, importance, and pleasantness of colors. According to the Mann-Whitney U tests, there was no difference in the usefulness, understandability, importance, and pleasantness of colors between those who preferred the Guidance Prototype and those who preferred the Explanation

Prototype. As indicated by the usefulness rating on the color changes that is on the high side ($M=4.29$, $SD=0.81$), color changes were highly rated as useful by participants regardless of the prototype they preferred.

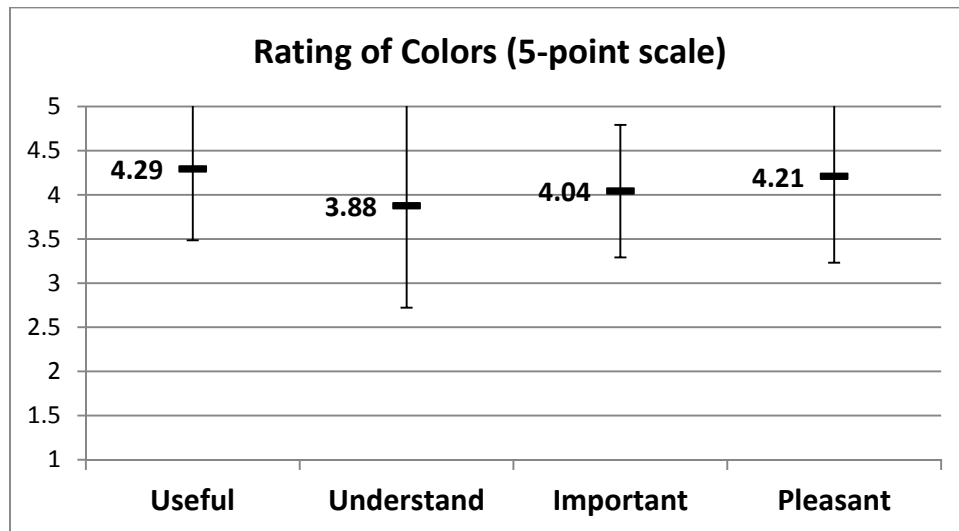


Figure 2.9. Usefulness, Understandability, Importance, and Pleasantness of colors, as rated by 24 participants, with SD as error bars

Figure 2.10 shows the usefulness, understandability, importance, and pleasantness of sounds (Speed Up, Slow Down). According to the Mann-Whitney U tests, there was no difference in the rating of sounds between those who preferred the Guidance Prototype and those who preferred the Explanation Prototype. Overall the sounds were rated as neutral ("So-so"), e.g. usefulness of Speed Up ($M=3.50$, $SD=0.82$) and Slow Down ($M=3.38$, $SD=0.5$).

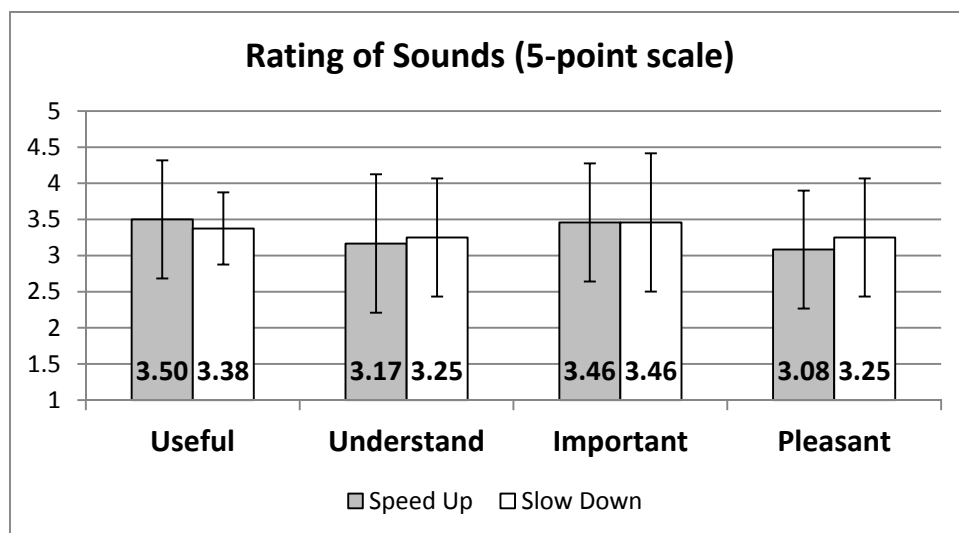


Figure 2.10. Usefulness, Understandability, Importance, and Pleasantness of sounds, as rated by 24 participants, with SD as error bars

A Friedman test was conducted in order to evaluate whether there was a difference in usefulness rating between user interface elements: colors, buttons, icons, and sounds. The result is significant ($X^2(4)=16.118$, $p=.003$). Figure 2.11 shows that color changes ($M=4.29$) were rated as more useful than the Slow Down sound ($M=3.38$, $Z=-3.752$) and the Speed Up sound ($M=3.5$, $Z=-3.497$), as indicated by Wilcoxon Signed Rank tests (both $p<.001$).

Similarly for the pleasantness of the interface elements, the Friedman test showed a significant result ($X^2(4)=13.73$, $p=.008$). Figure 2.12 shows that color changes ($M=4.21$) were rated as more pleasant than the Slow Down sound ($M=3.25$, $Z=-3.069$) and the Speed Up sound ($M=3.08$, $Z=-3.348$) as indicated by Wilcoxon Signed Rank tests ($p=.002$ and $p=.001$ respectively). Therefore, color changes were rated as more useful and pleasant than sound signals.

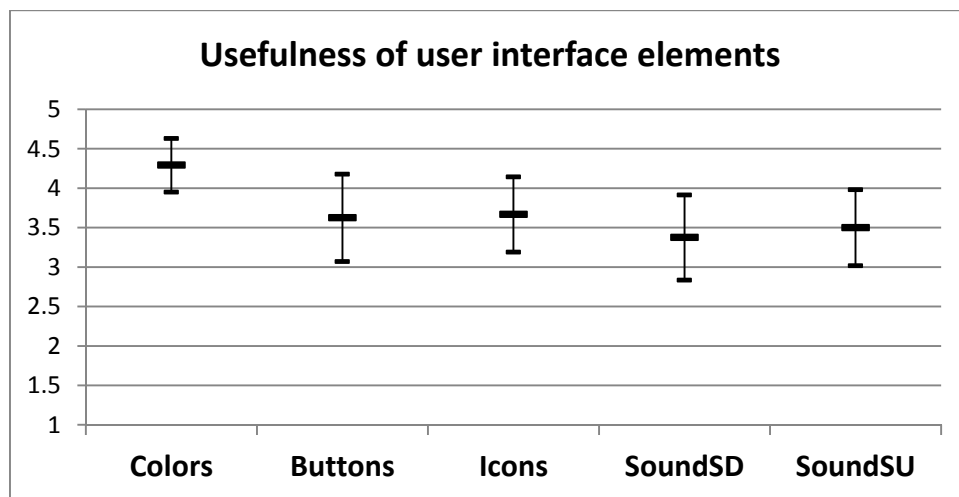


Figure 2.11. Usefulness of colors, buttons, icons, Slow Down sound, Speed Up sound, as rated by 24 participants, with 95% confidence interval

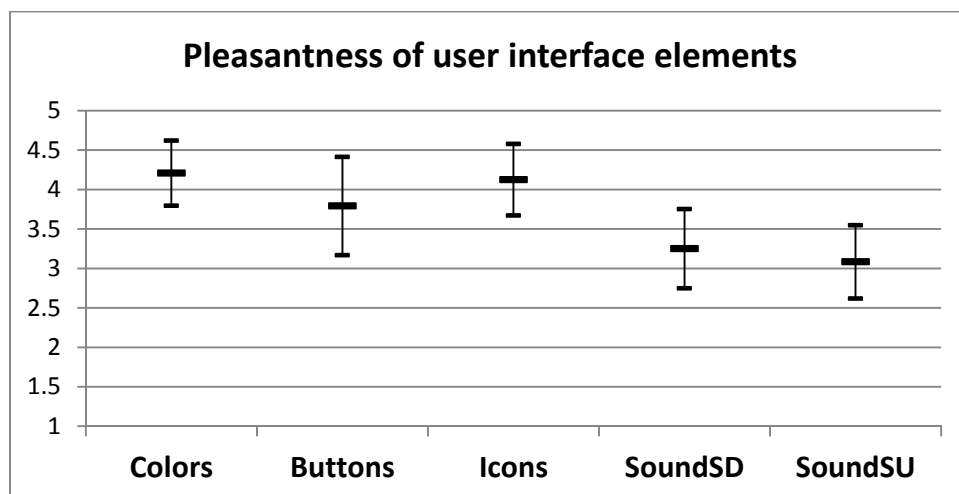


Figure 2.12. Pleasantness of colors, buttons, icons, sound Slow Down, sound Speed Up, as rated by 24 participants, with 95% confidence interval

To answer the question whether participants could map three different levels of urgency using the prototypes, an investigation was performed on the result of the questionnaire items about sensing urgency. Because interaction effects cannot be observed with a non-parametric test, a two-way repeated measures ANOVA was conducted on the sensing low urgency, sensing medium urgency, and sensing high urgency ratings for both prototypes. There was no difference among sensing low, medium, and high levels of urgency, but there was a difference between the Guidance prototype and the Explanation prototype ($F_{1,23}=4.262$, $p=.05$). There was no interaction effect between levels of urgency and prototypes. Post Hoc analysis showed that the Explanation prototype ($M=3.4$) was rated higher than the Guidance prototype ($M=3.05$). This indicated that the Explanation prototype was considered more helpful than the Guidance prototype for sensing urgency.

To answer the question about what users considered as more triggering to take actions upon the device's feedback, an investigation was performed on the result of the questionnaire items about taking action. A Wilcoxon Signed Rank test showed that participants judged the color changes as influencing them to take action more than sound signals ($p=.033$). On acting upon the sounds, a Mann-Whitney U test between those who preferred the Guidance Prototype and those who preferred the Explanation Prototype was computed. There was no difference between them in terms of acting on the sounds. Similarly, there was no difference between them in terms of acting on the color changes.

2.4.4. Results – Qualitative

What

On the basis of the post-test interview it can be concluded that the reason for preferring the Explanation prototype over the Guidance prototype was the usefulness of the traffic information, which participants described as "helpful" and "easier to follow". "Easier" was understood as having more comprehension of the traffic situation, thus they were more inclined to follow the device's advice.

Most participants mentioned that Traffic Jam and Warning are the most important (urgent) information to be communicated through the CSA device. Only a small number of participants regarded a traffic jam as not urgent at all, because it can be managed by a PND. Warning information was best understood when it concerned 'exceeding the speed limit' and 'dangerous road ahead'.

Most participants mentioned Merging In Front and Merging Behind as less important than Traffic Jam and Warning. They indicated that this kind of information is only useful for beginners; the information about other cars' behavior changes too frequently; they are only relevant for others – not beneficial to

themselves; and it is more suitable for automated systems. There were other opinions on the difference between the two. Some participants mentioned Merging Behind as less important than Merging In Front, while some others considered Merging behind more important, because of the fact that it comes from behind "you're not looking at the mirror all the time".

Some participants ($N=3$) mentioned the possibility of combining the CSA system with a PND system for re-routing when a road is unavailable or contains disturbances, also because they do not want to have two devices. Participants mentioned possible warnings for collision, blindspot, reasonable advice, and warnings for events not directly observable by drivers.

When

Further discussion with some participants regarding the existing information resulted in several ideas. Some participants remarked that each advice should have a period of validity, "When can I start to speed up again?" Some of them desired less frequent advice. Some of them desired explanation before using the device and extra information to help beginners. One of them mentioned that such a speed up advice is not necessary, because a driver is usually too slow due to distraction (there is no need to add more distraction).

How

The usefulness of colors was frequently mentioned during the interview, described as "I cannot miss it", or "It was always there". Red was considered very meaningful, while white was preferred over other basic colors (participants mentioned "green" and "blue"). Only one participant expected the color changes to be modified, i.e. the white one (for Too Slow) modified into something else (the participant could not give an example). Some participants ($N=3$) suggested combining colors and sounds: 1) Combination of colors and sounds can be helpful in showing different urgency situations; 2) Colors can be red for both Too Slow and Too Fast conditions but with different sound signals. Only some participants ($N=3$) mentioned that no display is needed, just sounds, mostly because of their preference for looking at what is happening on the road.

Almost a third ($N=7$) of the participants did not like the sound signals. They preferred no sounds or they suggested improving the current sounds to become more pleasant or by making them more simple/clear, like "ping" and "pong" (signal consisting of only one burst). Some participants ($N=3$) suggested the following: 1) Sounds should immediately convey a meaning on which action to take; 2) Sounds can be used to notice the driver to look at the device.

Some participants ($N=3$) mentioned that the speed bar confused them. The difference between the displays of Too Slow (left) and Too Fast (right) caused them to notice the recommended speed on different locations on the screen.

Some participants ($N=6$) mentioned that buttons are not needed, because the speech commands can be displayed without any buttons. Their suggestion for the speech messages was as follows: 1) Speech messages can also be a threat "You will get a fine if you do not do this"; 2) Speech messages are appropriate for high urgency situations.

2.5. Conclusion and Discussion

This first study explored the use of different user interface elements in a portable driving assistance system: color changes, icons, buttons, and sound signals. This study also tested the CSA prototypes: the Explanation Prototype and the Guidance Prototype. The results showed that 15 out of 24 participants preferred the Explanation Prototype and 9 participants preferred the Guidance Prototype.

From the qualitative analysis, it was found that the Guidance prototype was considered subtle and less distracting. The fact that more users preferred the Explanation Prototype does not mean that they wanted an obtrusive device. What they liked from the prototype is the extra information. Extra information is useful and motivates people to take action. This was confirmed by the quantitative analysis, indicating that the Explanation Prototype was judged as making it easier to distinguish urgency than the Guidance Prototype. This may be due to the extra information itself, so that users can distinguish one situation from other situations.

In the prototypes used in this exploratory study, information was updated every 2 seconds (as addressed in Section 2.4.1). Some participants would like to receive less frequent advice, indicating an issue with the rate of information update. However, the annoying auditory signals might have been a confounding factor. Especially with auditory advice, a longer interval between advices needs to be considered.

It was found that participants preferred receiving extra information through speech instead of through anything visual (icons or texts). The literature (Federal Highway Administration, 2004) suggests that speech is useful for navigation instructions or non-urgent messages. Participants also found that buttons were distracting. Literature (Bach, Jæger, Skov, & Thomassen, 2008; Johnson, Koh, McAtee, & Shoulders, 2007; Lin, Hwang, Su, & Chen, 2008) shows that usage of buttons, especially buttons on touch screens in the car, is not preferred by users. Moreover, it appears from our test that the interactions between participants and the prototypes were too intense. The information updates from the road were quite frequent, so it

was not practical for certain participants to request additional information through the buttons all the time. This explains why participants preferred not to press extra buttons and suggested that the device should show extra information automatically.

With respect to human's cognitive abilities, color changes were found to increase the salience of dynamic visual information. The changes in the large colored area were not easily missed by test participants, indicating that the color changes in their peripheral vision (instead of central vision) caught their attention. Color changes triggered participants to take actions and comply with the advice given by the device.

The result of the evaluation of the color changes confirmed the result of a study by Matthews (2007) that investigated glanceable visual display consisting of different types of visual symbolism (simple graphics, complex graphics, and colors). The study reported that color-based symbolism supported the usage of peripheral vision alone 90% of the time (only 10% glance, i.e. least distraction from main task) for a set of three symbols.

The quantitative analysis showed that participants judged color changes as more effective than sounds in making them comply with the advice of the CSA prototypes. Participants rated both Slow Down and Speed Up sounds equally neutral. Using color changes to distinguish between Too Slow and Too Fast was considered sufficient. If sounds are used for informing every single Too Slow and Too Fast states, the meaning of the sounds become redundant and users may become unaware of the sounds. Therefore, sounds should not be used for conveying the same information as what the color changes already convey.

There were no differences between people who preferred the Guidance Prototype and people who preferred the Explanation Prototype on the ratings of colors, icons, and buttons. People from both groups had mixed opinions that were comparable.

Participants could not map three levels of urgency situations (low, medium, high) using the prototypes. Possibly, in more urgent situations, using one single sound is good for notifying drivers to look at color changes. A combination of peripheral visual information and sounds would be useful to distinguish different urgency levels. The urgency levels conveyed through the device may also have to be simplified to low and high only, so they will be easily distinguishable from each other.

2.6. Recommendation for the Next Step

Recommendations are compiled as input to the future design iterations. The recommendations are: Use alerting stimuli through peripheral vision (e.g. color changes); Use extra information for persuading users to take actions; Use no buttons on the interface, except buttons for settings (not to be used while driving), thus avoiding problems with touch screens.

The auditory interface needs to be improved by encoding urgency levels in the sounds. The redesigning of the auditory interface is discussed in Chapter 3.

In this exploratory study, we only used subjective data for evaluating the design of CSA prototypes. In the next step, the evaluation method can be improved by including objective data for supporting evaluation results. The objective data should show the actual behavior of users during evaluation, in addition to subjective judgment or self-report. This way, the effects of different interfaces on the performance of drivers can be better established. The improved evaluation method is addressed in Chapter 4.

Urgency levels are to be simplified to low and high. Redundancy, or the use of the auditory interface for the same purpose as the other interface modality (e.g. color changes) is to be removed from future designs. Instead, the complementary use of colors and sounds for different urgency levels should be investigated. Improving the speed indicator in order to show how much the current speed differs from recommended speed can also help in sensing urgency. Therefore, the visual information about current speed and recommended speed also needs to be improved. This issue is discussed in Chapter 5.

3

Design of Auditory Messages for Speed Advice

Auditory signals, like simple tones and speech messages have been used in in-car systems for quite a few years. Simple tones are mostly used for status indication or warning and alerting purposes. We propose that simple tones can also be used for the purpose of advising drivers through an Advanced Driver Assistance System (ADAS). The ADAS application is Cooperative Speed Assistance (CSA), where drivers receive advice to slow down or speed up to coordinate their speed with the speed of other vehicles in the traffic. Two concepts of auditory messages are presented: Looping messages, which are played as long as the advice applies; and Toggle messages, which mark the beginning and end of an advice. For each concept, two prototypes of simple-tone signals were designed based on existing guidelines about sound characteristics affecting urgency and evaluation by users. The temporal characteristics of the signals indicated how much or how fast drivers should adapt their speed. The auditory concepts were evaluated by having users drive in a driving simulator without any visual advice to slow down or speed up. Objective measurements indicated that there was no difference in effectiveness between the two concepts. Subjective evaluation indicated that users preferred the Toggle concept.³

³ This chapter is based on:

Shahab, Q., Terken, J., Eggen, B. (2010). *Auditory Messages for Speed Advice in Advanced Driver Assistance Systems*. Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp.50-56). Pittsburg, USA, ACM Press.

3.1. Introduction

Auditory signals have been used for In-Vehicle Information Systems (IVIS) and Advanced Driver Assistance Systems (ADAS) for quite a few years. An example of the use of auditory signals is provided by navigation systems, where speech messages are used to inform drivers about which direction to take. According to Federal Highway Administration (2004), there are several types of auditory signals: simple tones, earcons, auditory icons, and speech messages. While speech messages are mostly appropriate to display qualitative and quantitative information, simple tones are best for status indication and alerting (attentional) signals.

In the previous chapter (Chapter 2), we outlined the exploratory design of an aftermarket device called Cooperative Speed Assistance (CSA) involving visual and auditory feedback. CSA is to be developed as a nomadic device. The choice for a nomadic system was based on the assumption that it favors a faster market penetration, so that more vehicles in the traffic can be equipped with the speed regulation system and the beneficial effects on traffic flow occur at a faster rate. In cooperative driving there are no fixed speed limits, but the recommended speed always changes according to the traffic condition. In such situations drivers need simple and clear speed advice such as Slow Down and Speed Up.

Moreover, in case of nomadic systems, the use of the haptic modality to inform drivers is limited. This leaves us with easily available modalities for aftermarket devices: visual and auditory. We would like to investigate opportunities for using non-speech auditory messages to provide speed advice to drivers. This chapter continues from the previous chapter where non-speech auditory messages were explored, resulting in the need of including urgency coded in the signals. In this chapter, we investigate the appropriate auditory feedback to be used in the CSA system.

The literature reports evaluations of several speed management systems such as the Intelligent Speed Adaptation system (ISA) (Adell et al., 2008). In one experiment, haptic and auditory feedbacks for a speed management system were compared and the result indicated that the majority of drivers preferred to keep the auditory beep system even though it showed lower satisfaction ratings than the haptic pedal system. This result shows the acceptability of using auditory feedback in speed management systems.

A recommendation by Deatherage (1972) as cited by Stanton & Edworthy (1999) is to use the auditory modality if: the message is simple, short, and transient; the message deals with events in time; the message calls for immediate action; or the visual system is overburdened. This recommendation properly fits to the driving context where the visual system may be overburdened. In this respect, the auditory modality

has an advantage over the visual modality, as indicated by the result of a study by Sodnik et al. (2008), where a visual interface distracted users from performing the primary task of driving, thus reducing its efficiency.

Several additional advantages may be listed for the auditory modality compared to the visual modality in driving. In the first place, the auditory modality allows for a faster reaction of drivers toward in-vehicle messages compared to a Head Down Display (Horrey & Wickens, 2004), which is the only visual display solution currently available in aftermarket IVIS/ADAS. Another advantage of the auditory channel in the context of ADAS is that it is omnidirectional (Sarter, 2006), as auditory information can be picked up comfortably while driving, where users are not supposed to change their head or body orientation. Furthermore, it is impossible for people to “close their ears”, so that the auditory channel is good for alerting functions. Finally, the sensory memory for the auditory channel lasts longer than for the visual channel, so that auditory information can be processed even after some delay (Wickens, Lee, Liu, & Gordon-Becker, 2004).

In a recent user test with a speed advice system (van den Broek, Netten, Hoedemaeker, & Ploeg, 2010), speech messages were used to inform drivers about recommended speed, but the use of speech appeared annoying. This adds up to the anecdotic evidence that the use of speech messages in the car is fraught with difficulties, as it is easily considered annoying by drivers. In addition, non-speech warnings allow for a wider range of urgency indication compared to speech warning (Edworthy, Walters, Hellier, & Weedon, 2000). Therefore, we will explore the use of non-speech auditory signals.

The messages in the CSA system, although advisory, also need to be alerting to drivers. Other than simple tones, using auditory icons (Gaver, 1989) and earcons (Blattner, Sumikawa, & Greenberg, 1989) can be considered, but we argue that they are not appropriate for the context of CSA. The following paragraphs about auditory icons and earcons explain our arguments.

Auditory icons resemble sounds from everyday life, where attributes of the sound-producing events are mapped onto attributes of the model world in the computer (Gaver, 1989). An example of an auditory icon is the sound of crunching paper while deleting a document in the Windows operating system. It is difficult to derive such sounds from the Too Slow and Too Fast events in cars. The use of engine sounds to represent too slow or too fast engine load is considered a drawback, because existing technology has managed to insulate passengers from loud engine sounds. Although the use of auditory icons for alerting messages is promising (Belz, Robinson, & Casali, 1999), it still needs to be re-investigated for the car context (Graham, 1999).

Earcons are structured audio messages analogous to visual icons. According to Blattner, Sumikawa, & Greenberg (1989), there are two types of earcons: representational (actually auditory icons as defined by Gaver) and abstract (based on musical motives). An example of an abstract earcon is the sound of drum roll preceding an important presentation. Studies found that the use of abstract earcons in the car leads to longer response times (Vilimek & Hempel, 2005) and takes longer to learn (Fagerlönn & Alm, 2010) compared to the use of auditory icons. In order to simplify the design space of earcons, we choose only pitch from the parameters of abstract earcons (rhythm, pitch, timbre, register). This reduces earcons to simple tones.

The use of simple tones is considered appropriate for our design requirement, which is to give two basic messages: Slow Down and Speed Up. The exact target speed may then be communicated through the visual display in the system, because it does not need timely response.

This chapter presents the sound design we followed. The concepts for in-car auditory signals are proposed and the design of the simple tones is explained in Section 3.2. Section 3.3 describes a test aiming to evaluate the concepts of displaying the auditory advice while driving without any visual advice. The results are presented in Section 3.4. The conclusion and discussion section follows in Section 3.5.

3.2. Sound Design

3.2.1. Guidelines

One of the properties that can be delivered by auditory signals is urgency. In the CSA system, the messages Slow Down and Speed Up should bear the message indicating how much to slow down or speed up, as the difference between the current and the advised speed can be larger or smaller.

Studies on manipulating sound characteristics to manipulate urgency levels have provided several guidelines, such as: higher pitch means higher urgency, shorter inter-pulse interval means higher urgency, faster tempo means higher urgency (Edworthy, Hellier, & Hards, 1995; Hellier, Edworthy, & Dennis, 1993). When the urgency is higher, people also react faster to the auditory signals (Edworthy, Hellier, Walters, Weedon, & Adams, 2000; Suied, Susini, & McAdams, 2008). This way, urgency can be appropriately related to how much slower/faster people react to an auditory signal. Therefore, we designed the auditory signals for CSA by incorporating urgency as the main parameter to be conveyed by the Slow Down and Speed Up messages. We also developed auditory signal prototypes following a user-centered design approach as proposed by Edworthy & Stanton (1995). This design approach provides methods to evaluate and test the prototypes by users.

For the purpose of sound prototyping, we referred to the terms pulse, burst, and signal as proposed by Patterson (1982) cited by Stanton & Edworthy (1999). A pulse is a complex harmonic tone with a specific fundamental frequency, a burst consists of repetition of pulses combined with inter-pulse (silence) periods, and a signal consists of a series of bursts combined with inter-burst (silence) periods. A graphical illustration of the terms is shown in Figure 3.1.

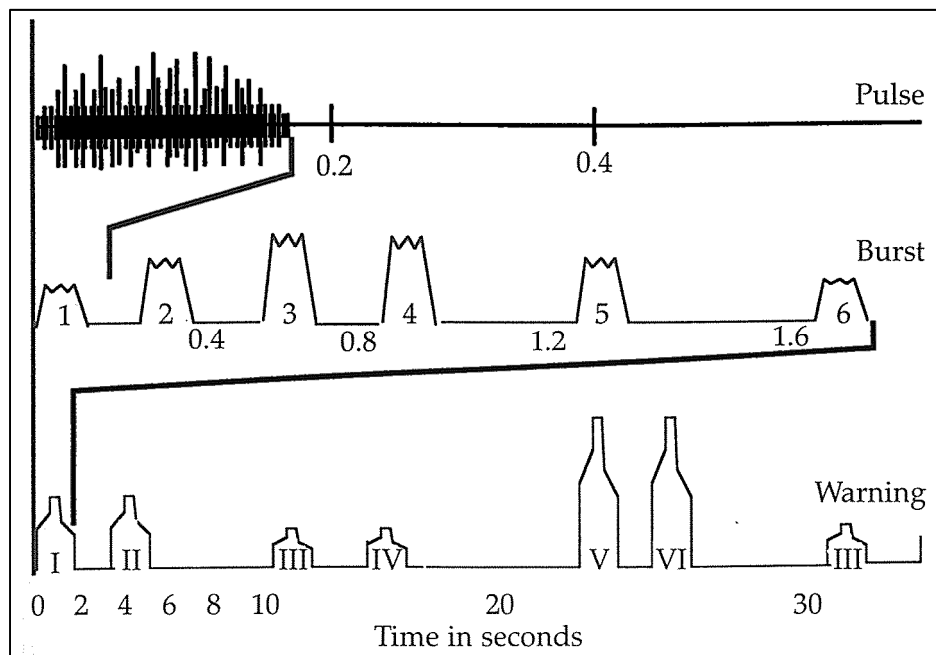


Figure 3.1. Pulse, Burst, and Warning Signal by Patterson (1982) as in Stanton & Edworthy (1999) pp.13

3.2.2. Concept

Four designers (two with expertise in sound design) were invited to discuss ideas for Slow Down and Speed Up messages for CSA. Three concepts were suggested: Continuous signals, Looping signals, and Toggle signals. Continuous signals give continuous information whether the driver needs to slow down or speed up or whether the speed is OK; that is, the signals are always heard inside the vehicle. This concept was dropped as it would be too annoying. Looping signals and Toggle signals were chosen for the design to be composed of simple tones.

In the Looping concept, when an advice needs to be given, an auditory signal is displayed. This signal expresses a certain urgency level that tells the driver about how much to slow down / speed up. The signal is repeated (looping) with decreasing urgency as the driver executes the advised task of meeting the target speed. A black square in Figure 3.2 indicates one signal. The black square of the same size is repeated, indicating a repetition of the signal of the same duration. The fading shade of the black squares indicates decreasing urgency.

In the Toggle concept, when an advice needs to be given, an auditory signal is displayed. This signal expresses an urgency level that tells the driver about how much to slow down / speed up. The driver needs to slow down / speed up until an OK signal is displayed, informing her/him that s/he has reached the target speed. In Figure 3.2, the black square represents the message to slow down / speed up, and the green square represents the OK signal.

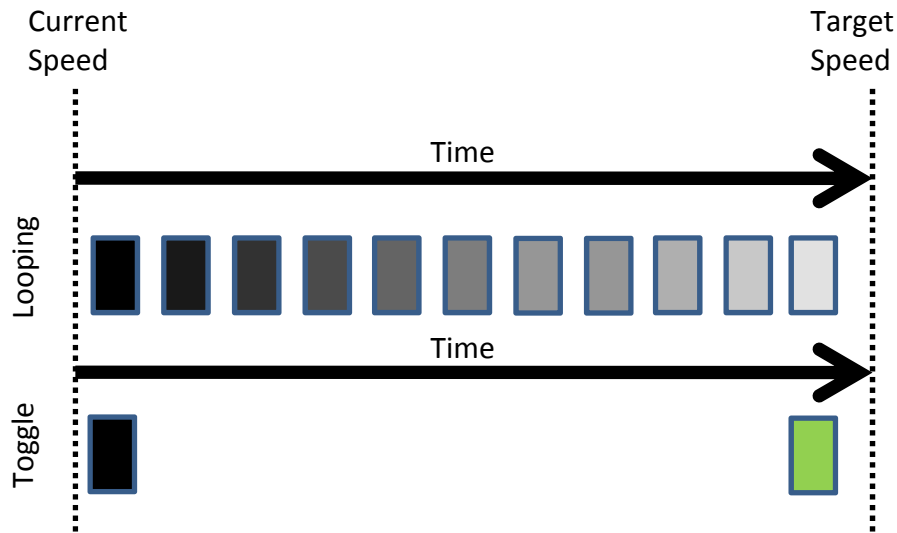


Figure 3.2. Concept illustration of Looping signals and Toggle signals.

A potential disadvantage of the Toggle concept compared to the Looping concept is that it is displayed only in the beginning, so that the instruction needs to be retained in working memory, potentially causing extra mental workload. In the case of a very long period between current speed and target speed, it is discussed in Section 3.3.1 whether the signal should be repeated after a certain period of time.

3.2.3. Burst Design: First Iteration

In order to compose a burst, a number of pulses were designed. Four complex harmonic tones (pulses) were constructed consisting of sine waves of 60 degree phase using GIPOS (Gigi, 2001) with fundamental frequencies of 400Hz, 500Hz, 600Hz, and 800Hz. For each fundamental frequency, the duration was varied: 100ms, 200ms, and 400ms, resulting in a total of 12 pulses. To prevent abrupt onsets and offsets on each pulse, a fade in effect of 20ms (onset time) and a fade out effect of 100ms (offset time) were applied on each of them.

From the 12 pulses, 4 sets of burst prototypes were designed. The main design considerations for the bursts were as follows. Pitch is used to code the direction of speed change, with rising pitch indicating an advice to speed up and falling pitch indicating an advice to slow down (as tested in the experiment described in Chapter 2). Urgency is coded by the duration of the pulses and the inter-pulse intervals. In order to find out the mapping between burst characteristics and urgency levels, we

tried three levels of urgency. Therefore, each of the four burst prototypes consisted of 6 variants, as a result of varying 3 different levels of urgency and 2 different directions of pitch change (falling and rising).

Table 3.1. The 4 sets of burst prototypes as varied by 3 different levels of urgency and 2 directions of pitch. The description {XHz[Yms], Zms} indicates a pulse of X frequency and Y duration, followed by an inter-pulse interval of Z duration. There are at least two lines in each table cell. The first line indicates the first pulse, and the second line indicates a following pulse, and so on. The bursts in Set 1 and Set 2 consist of two pulses, while the ones in Set 3 consist of three pulses and the ones in Set 4 consist of six pulses. Urgency levels 1, 2, 3 represent low, medium, high urgency respectively.

Prototype Set 1	Urgency Level 1	Urgency Level 2	Urgency Level 3
Falling pitch	800Hz[100ms], 50ms 600Hz[100ms], 50ms	800Hz[200ms], 100ms 600Hz[200ms], 100ms	800hz[400ms], 200ms 600hz[400ms], 200ms
Rising pitch	400Hz[100ms], 50ms 500Hz[100ms], 50ms	400Hz[200ms], 100ms 500Hz[200ms], 100ms	400Hz[400ms], 200ms 500Hz[400ms], 200ms
Prototype Set 2	Urgency Level 1	Urgency Level 2	Urgency Level 3
Falling pitch	800Hz[100ms], 50ms 600Hz[100ms], 50ms	600Hz[200ms], 100ms 500Hz[200ms], 100ms	500hz[400ms], 200ms 400hz[400ms], 200ms
Rising pitch	600Hz[100ms], 50ms 800Hz[100ms], 50ms	500Hz[200ms], 100ms 600Hz[200ms], 100ms	400hz[400ms], 200ms 500hz[400ms], 200ms
Prototype Set 3	Urgency Level 1	Urgency Level 2	Urgency Level 3
Falling pitch	800Hz[100ms], 50ms 600Hz[100ms], 100ms 400Hz[100ms], 100ms	800Hz[200ms], 100ms 600Hz[200ms], 200ms 400Hz[200ms], 200ms	800Hz[400ms], 200ms 600Hz[400ms], 400ms 400Hz[400ms], 400ms
Rising pitch	400Hz[100ms], 50ms 600Hz[100ms], 100ms 800Hz[100ms], 100ms	400Hz[200ms], 100ms 600Hz[200ms], 200ms 800Hz[200ms], 200ms	400Hz[400ms], 200ms 600Hz[400ms], 400ms 800Hz[400ms], 400ms
Prototype Set 4	Urgency Level 1	Urgency Level 2	Urgency Level 3
Falling pitch	500Hz[100ms], 50ms 400Hz[100ms], 50ms 500Hz[100ms], 50ms 400Hz[100ms], 50ms 500Hz[100ms], 50ms 400Hz[100ms], 50ms	500Hz[200ms], 100ms 400Hz[200ms], 100ms 500Hz[200ms], 100ms 400Hz[200ms], 100ms 500Hz[200ms], 100ms 400Hz[200ms], 100ms	500Hz[400ms], 200ms 400Hz[400ms], 200ms 500Hz[400ms], 200ms 400Hz[400ms], 200ms 500Hz[400ms], 200ms 400Hz[400ms], 200ms
Rising pitch	500Hz[100ms], 50ms 600Hz[100ms], 50ms 500Hz[100ms], 50ms 600Hz[100ms], 50ms 500Hz[100ms], 50ms 600Hz[100ms], 50ms	500Hz[200ms], 100ms 600Hz[200ms], 100ms 500Hz[200ms], 100ms 600Hz[200ms], 100ms 500Hz[200ms], 100ms 600Hz[200ms], 100ms	500Hz[400ms], 200ms 600Hz[400ms], 200ms 500Hz[400ms], 200ms 600Hz[400ms], 200ms 500Hz[400ms], 200ms 600Hz[400ms], 200ms

Several tests were conducted with six designers to evaluate various aspects such as learnability, confusability and identification of the Slow Down / Speed Up and urgency attributes. There were two learnability/confusability tests. In the first test

(Appendix B.1, Test 1a), each prototype was presented in three pairs of burst variants, where each pair consisted of variants from the same level of urgency but with different pitch direction. For each pair, evaluators could listen to the two sounds as many times as they liked in any order before identifying which one indicated Slow Down and which one indicated Speed Up. In the second test (Appendix B.1, Test 1b), each prototype was presented in six pairs of burst variants, where each pair consisted of variants of different levels of urgency of the same pitch direction. For each pair, evaluators could listen to the two sounds as many times as they liked in any order before identifying which one was perceived as more urgent than the other. In the identification test (Appendix B.1, Test 2), the six burst variants of each prototype were presented in a table. Evaluators were asked to label the meaning of each burst variant (Slow Down / Speed Up) and label it with one of the three levels of urgency. After the three tests were conducted, qualitative feedback was obtained by asking the evaluators about the relationships between sound characteristics and information attributes.

The urgency levels were less well understood, indicating a redesign is necessary. The source of confusion for the urgency levels was mostly related to the duration of the pulses and inter-pulse intervals. To most evaluators, shorter pulse duration meant higher urgency. However, they considered longer pulses to be more prominent or insistent or more salient than shorter ones, thus indicating that a more persistent signal implied higher urgency. It can be concluded that careful distinction should be made between the effects of the duration of the pulse and of the inter-pulse interval on perceived urgency level. If inter-pulse intervals are varied, then pulse duration should be made uniform among signals.

The qualitative feedback confirmed the finding in Chapter 2. As expected, the changes of pitch from high to low would be interpreted as Slow Down messages, and the changes of pitch from low to high would be interpreted as Speed Up messages.

3.2.4. Burst Design: Second Iteration

The four sets were redesigned into two sets. To overcome the problem of confusions between urgency levels, the pulse duration was set at a fixed value of 100ms. Only the duration of the inter-pulse interval was manipulated (decreasing duration = more urgent).

The description for the two sets of redesigned signals is illustrated by tables and figures. Prototype 1 consists of 6 bursts of 2 pulses each. Table 3.2 describes the Slow Down and Speed Up signals of 3 bursts each: low, medium, and high urgency. The graphical illustration of a medium urgency burst from a Slow Down signal and a Speed Up signal is shown in Figure 3.3. Prototype 2 consists of 6 bursts of 3 pulses each. Table 3.3 describes the Slow Down signal of 3 bursts: low, medium, and high

urgency. The graphical illustration of a medium urgency burst from a Slow Down signal and a Speed Up signal is shown in Figure 3.4.

Table 3.2.a. Burst Prototype 1, Slow Down: displayed in 3 variants representing Low, Medium, High urgency respectively.

Urgency	Pulse 1		Inter-pulse	Pulse 2		Inter-pulse
	f(Hz)	t(ms)		f(Hz)	t(ms)	
Low	600	100	400	400	100	400
Medium	600	100	150	400	100	150
High	600	100	0	400	100	0

Table 3.2.b. Burst Prototype 1, Speed Up: displayed in 3 variants representing Low, Medium, High urgency respectively.

Urgency	Pulse 1		Inter-pulse	Pulse 2		Inter-pulse
	f(Hz)	t(ms)		f(Hz)	t(ms)	
Low	600	100	400	800	400	400
Medium	600	100	150	800	100	150
High	600	100	0	800	100	0

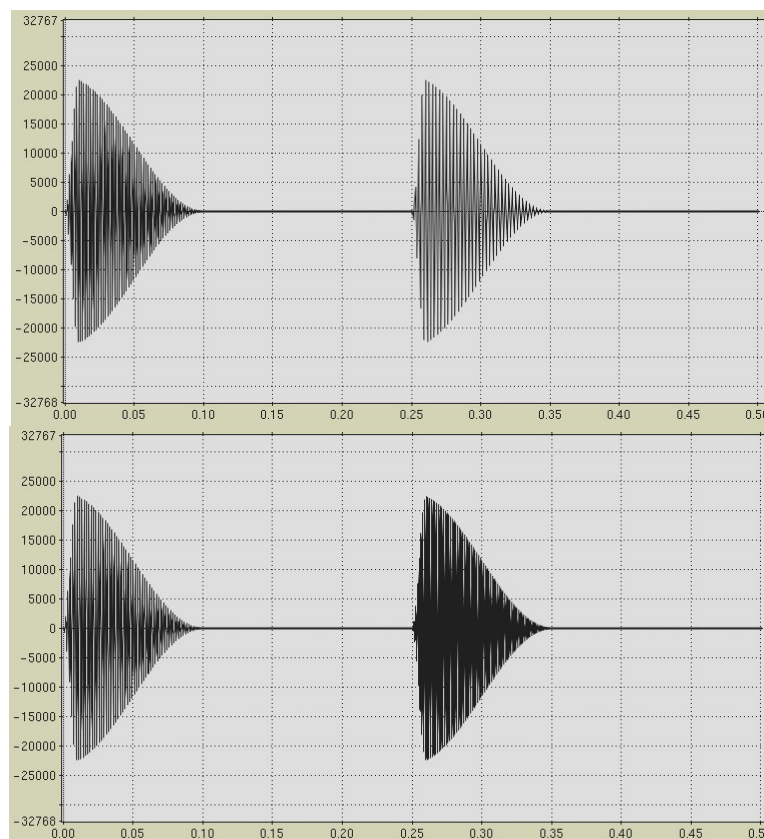


Figure 3.3. Burst Prototype 1 for medium urgency – Top: Slow Down (600Hz[100ms], silence[150ms], 400Hz[100ms], silence[150ms]); Bottom: Speed Up (600Hz[100ms], silence[150ms], 800Hz[100ms], silence[150ms])

Table 3.3.a. Burst Prototype 2, Slow Down: displayed in 3 variants representing Low, Medium, High urgency respectively.

Urgency	Pulse 1		Inter-pulse 1	Pulse 2		Inter-pulse 2	Pulse 3		Inter-pulse 3
	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)
Low	800	100	200	600	100	400	400	100	400
Medium	800	100	100	600	100	200	400	100	200
High	800	100	0	600	100	50	400	100	50

Table 3.3.b. Burst Prototype 2, Speed Up: displayed in 3 variants representing Low, Medium, High urgency respectively.

Urgency	Pulse 1		Inter-pulse 1	Pulse 2		Inter-pulse 2	Pulse 3		Inter-pulse 3
	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)
Low	400	100	200	600	100	400	800	100	400
Medium	400	100	100	600	100	200	800	100	200
High	400	100	0	600	100	50	800	100	50

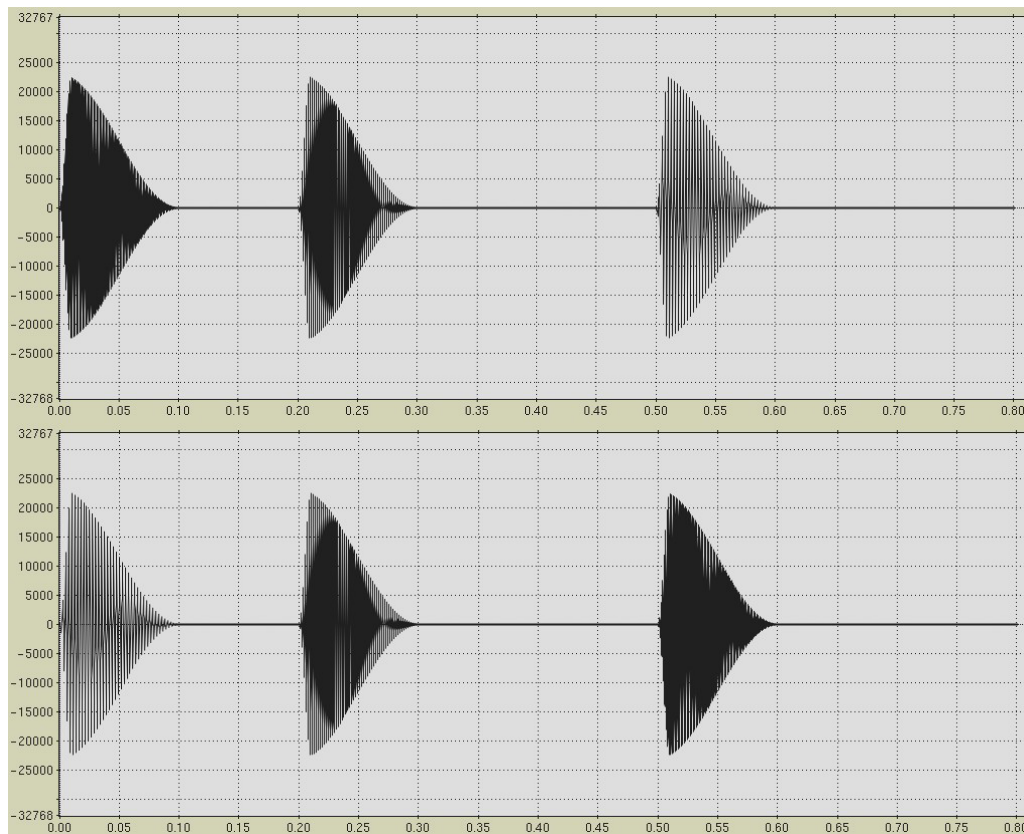


Figure 3.4. Burst Prototype 2 (3 pulses) for medium urgency – Top: Slow Down (800Hz[100ms], silence[100ms], 600Hz[100ms], silence[200ms], 400Hz[100ms], silence[200ms]); Bottom: Speed Up (400Hz[100ms], silence[100ms], 600Hz[100ms], silence[200ms], 800Hz[100ms], silence[200ms])

Both sets were re-evaluated with four designers (with the same tests as in Appendix B.1). At least 3 out of 4 evaluators distinguished the pairs in the sets correctly. Both the Slow Down / Speed Up messages and the urgency levels were recognized correctly. One evaluator expressed being confused about the Slow Down and Speed Up messages. The increasing pitch is supposed to signal an advice to Speed Up, but it might also be interpreted as signaling that the car is too fast and the driver needs to slow down (a Slow Down advice). The results also indicated that keeping the pulse duration constant and varying the duration of the inter-pulse interval has a strong effect on perceived urgency levels, which is in line with the recommendation of Edworthy, Loxley, & Dennis (1991).

Additional comments from evaluators indicate that the use of repeated bursts ensured equal audibility of all message types and urgency levels (two evaluators). One evaluator was unable to distinguish medium and low urgency signals but could still recognize the varied duration of inter-pulse intervals and used it as a basis for distinguishing urgency levels.

The two redesigned prototypes passed the learnability, confusability, and identification tests. They met the requirements of pitch changes for conveying Slow Down / Speed Up meaning, as well as uniform pulse duration and varied inter-pulse intervals for conveying different urgency levels. The next step was to evaluate the two prototypes in a realistic context with a driving simulator. For the experiment, the two prototypes were presented in the way of the two concepts: Looping and Toggle. The details of how the prototypes were constructed for the experiment are described in the following section (subsection 3.3.1).

For the purpose of the driving test, the OK signal for the Toggle concept was designed using a fundamental frequency of 550Hz of 100ms duration with two additional lower-amplitude pulses (delay effect) of 100ms each, making a total of 300ms duration of the signal. The waveform of the OK signal is shown in Figure 3.5.

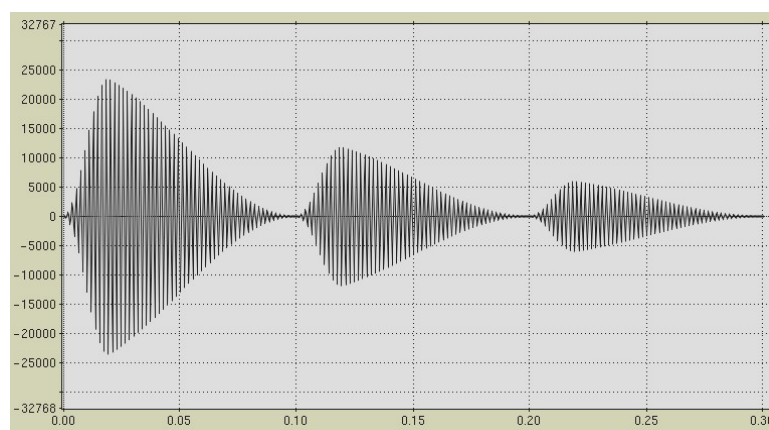


Figure 3.5. The OK signal of 300ms duration

It is “fairly important to impose some sort of experimental control over the stimuli so that some are not more noticeable than others on the basis of non-acoustic cues”, as noted by Edworthy & Stanton (1995). Therefore, the duration of signals should be held constant in order to overcome the problem of short urgent messages being easily missed by drivers. Because of the equal duration, shorter bursts are repeated more number of times than longer bursts. We decided to set the duration at 1500ms after studying the choice of durations in previous studies (Ho, Reed, & Spence, 2007; Marshall, Lee, & Austria, 2007; Mohebbi et al., 2009; Wiese & Lee, 2004). This duration value is used for displaying the signals in the Toggle concept, because the Looping concept displays the signals for as long as the advice applies. In other words, each signal in the Toggle concept is displayed for 1500ms and followed by a silence until the driver complies with the advice.

3.3. Driving Simulator Test

3.3.1. Preparation

For the purpose of the experiment, we developed sound-displaying software connected to a medium-fidelity fixed-base driving simulator (Greendino, 2010). The software generated Slow Down and Speed Up messages by displaying pulses with the designed fundamental frequencies and inserting different inter-pulse silence periods between the pulses and inter-burst silence periods between the bursts. In order to allow distinction between bursts, the inter-burst intervals were set twice as long as the inter-pulse intervals. The distinction is needed so that drivers would not confuse between the beginning and the middle of a burst.

The inter-pulse intervals were generated real time based on how much the current speed is faster/slower than the target speed given by the traffic in the simulator. The minimum inter-pulse interval was 50ms (most urgent) and the maximum inter-pulse interval was 1000ms (least urgent). The millisecond value of the inter-pulse interval was obtained from 500 divided by the absolute value of speed difference multiplied by 10. This calculation considers 100 km/h as the maximum speed difference ($500/100 \times 10 = 50$) and 5 km/h as the minimum speed difference ($500/5 \times 10 = 1000$). This scale is continuous, as shown in Figure 3.6.

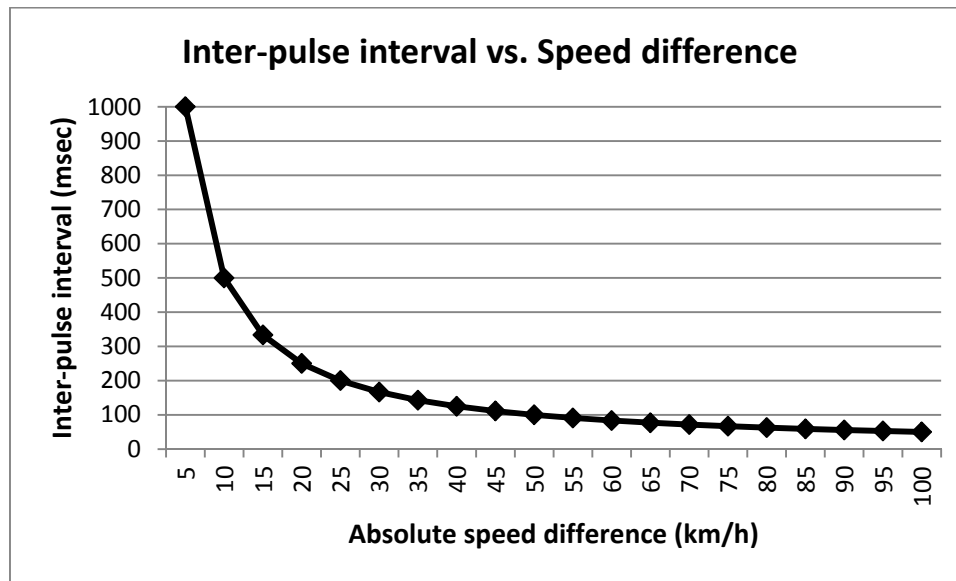


Figure 3.6. The real-time generation of inter-pulse interval based on the speed difference between current speed and target speed

Table 3.4 and Table 3.5 describe how Prototype 1 and Prototype 2 were generated by the software respectively. The tables show relationships between the speed difference and the duration of the sound signal. The tables use the Looping concept in order to show the duration of each sound signal that gets repeated until the driver complies with the advice. In the case of the Toggle concept, each sound signal shorter than 1500ms gets repeated for a total period of 1500ms. In the case of signals longer than 1500ms, they are not completely displayed. However, signals longer than 1500ms should convey enough information, because even for the lowest urgency the signals are displayed until the 2nd pulse (see the last row of Table 3.4 and Table 3.5).

Table 3.4. Prototype 1 (2 pulses) for Slow Down advice as displayed in the Looping concept. In the case of Toggle concept, the complete signals are displayed from 100km/h up to 15.4 km/h speed difference.

Urgency	Pulse 1		Inter-pulse	Pulse 2		Inter-pulse	Inter-burst	Duration
	f(Hz)	t(ms)		f(Hz)	t(ms)			
Highest (100 km/h)	600	100	50	400	100	50	100	400
Medium (33.33 km/h)	600	100	150	400	100	150	300	800
Low (15.4 km/h)	600	100	325	400	100	325	650	1500
Lowest (5 km/h)	600	100	1000	400	100	1000	2000	4200

Table 3.5. Prototype 2 (3 pulses) for Slow Down advice as displayed in the Looping concept. In the case of Toggle concept, the complete signals are displayed from 100km/h up to 18.75 km/h speed difference.

Urgency	Pulse 1		Inter-pulse/2	Pulse 2		Inter-pulse	Pulse 3		Inter-pulse	Inter-burst	Duration
	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)	f(Hz)	t(ms)	t(ms)	t(ms)	t(ms)
Highest (100 km/h)	800	100	25	600	100	50	400	100	50	100	525
Medium (33.33 km/h)	800	100	75	600	100	150	400	100	150	300	975
Low (18.75 km/h)	800	100	133	600	100	267	400	100	267	533	1500
Lowest (5 km/h)	800	100	1000	600	100	1000	400	100	1000	2000	5300

The OK signal is displayed as soon as the driver complies with the advice (his/her speed is less than 5 km/h faster/slower than the target speed). As mentioned at the end of Section 3.2.2, a too long period between the signal and the compliance of the advice may cause mental load. As the finding of Chapter 2 suggests that 2 seconds is too short to repeat another advice for drivers, we decided to investigate longer interval: 5 seconds. Therefore, if the driver does not comply with the advice in 5 seconds, another 1500ms signal is displayed again as a reminder.

3.3.2. Procedure

Twelve drivers (4 female, 8 male, age 20-29) were invited to participate in the driving experiment. In order to test the Slow Down and Speed Up messages, the experiment task for each participant was to drive freely using the prototypes. Participants were informed that CSA would assist them in adapting their speeds to other vehicles in order to create a smooth traffic. The target speed of CSA was taken from the speed of the preceding car, and this speed was varied by different speed limits on different road segments in the simulator track. Unlike the setting of the exploratory study in Chapter 2, there was no visual display of target speed. The only other visual displays were the main screen showing the road-traffic condition and the secondary screen showing the speedometer, as shown in Figure 3.7.

In the beginning of the experiment, each participant spent up to 5 minutes driving to get used to the driving simulator. Then they drove four additional rounds using the two prototypes in Looping and Toggle concepts. This took them driving four 5-minute time blocks where in each block they experienced one of the following conditions: Prototype 1 in the Looping concept, Prototype 1 in the Toggle concept,

Prototype 2 in the Looping concept, and Prototype 2 in the Toggle concept, consecutively. The order of conditions was balanced across participants.

After each 5-minute time block, participants were asked to rate their mental effort while driving using the system compared to normal driving, among other things because the Looping and Toggle concept may induce different degrees of mental load. The rating was measured by the Rating Scale for Mental Effort (RSME) scale (Zijlstra & van Doorn, 1985), as in Appendix B.2.

After each RSME rating, participants were also asked to rate the recognizability of the urgency, the annoyance, and the appropriateness of each condition (combination of concept and prototype). Appropriateness is a perceived measurement of whether urgency is sufficiently conveyed while minimizing annoyance (Marshall et al., 2007). The scale for each rating was from 0 to 10, so the urgency recognition ranged from no urgency detected to always detected urgency, the annoyance ranged from not annoying to always annoying, and appropriateness ranged from not appropriate at all to fully appropriate (see Appendix B.3 for the rating form).



Figure 3.7. The driving simulator setting for the auditory experiment, showing 5 monitors as the display of road-traffic and 1 monitor as the display of speedometer

At the end of the test, participants were interviewed in order to obtain a preference of interface and prototype as well as discuss the reasons and the difference between the interfaces and prototypes. Participants received a small fee based on 30 minute participation.

The behavior of participants while driving was also measured (objective measurement). The response of participants to every speed advice was logged.

3.3.3. Results – Subjective Measurements

Based on multivariate tests, there was no significant difference between RSME ratings by participants on each system, between concepts and between prototypes. It showed that each concept and prototype was rated as “some effort”. The means for each concept and prototype ranged from 32.75 to 37.83, as shown by Figure 3.8. No correlation was found between annoyance and RSME ratings, as well as urgency recognizability and appropriateness.

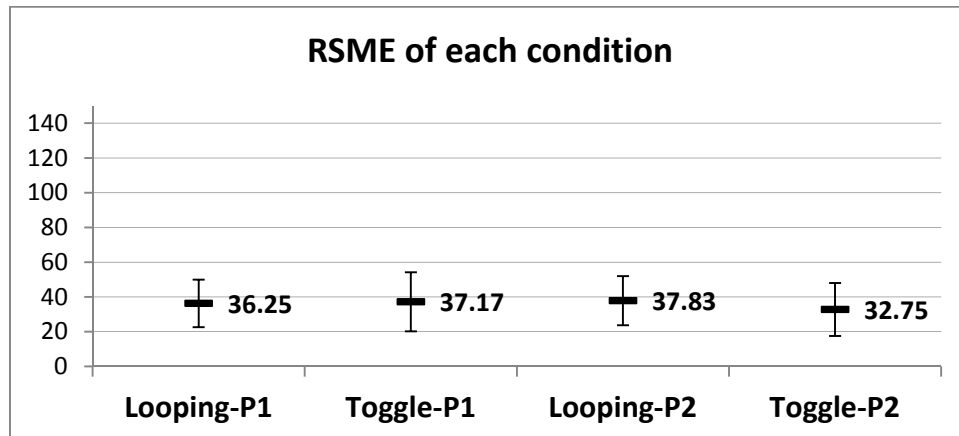


Figure 3.8. Average RSME rating per condition (concept-prototype), with \pm SD as error bars

Repeated measures analysis showed that there were no significant differences in urgency recognizability, annoyance, and appropriateness between concepts and between prototypes. Across all conditions, the means (on a scale from 0 to 10) for annoyance was 4.25 ($SD=1.84$), for appropriateness was 5.75 ($SD=1.52$), and for urgency recognizability was 6.29 ($SD=2.42$). Post-hoc analysis showed that annoyance was rated lower than appropriateness and urgency recognizability ($F_{2,88}=14.498$, $p<.001$). The details of the annoyance, appropriateness, and urgency recognizability ratings can be seen in Figure 3.9, Figure 3.10, and Figure 3.11 respectively.

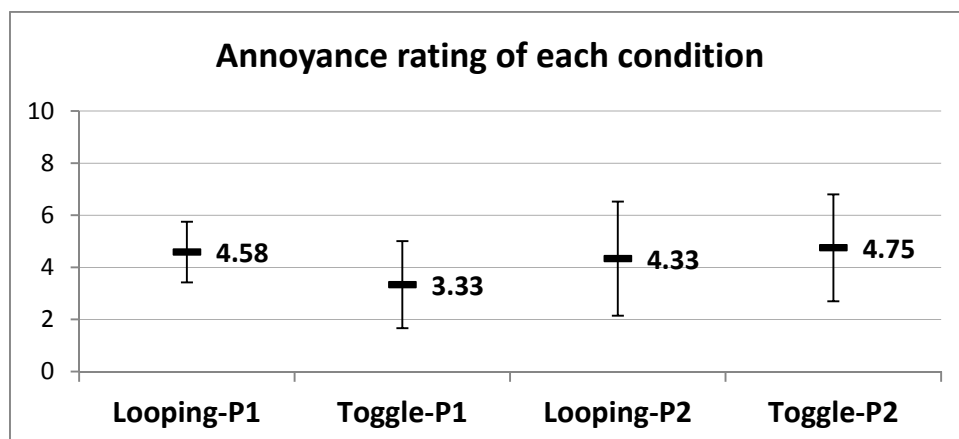


Figure 3.9. Average annoyance rating per condition (concept-prototype), with \pm SD as error bars

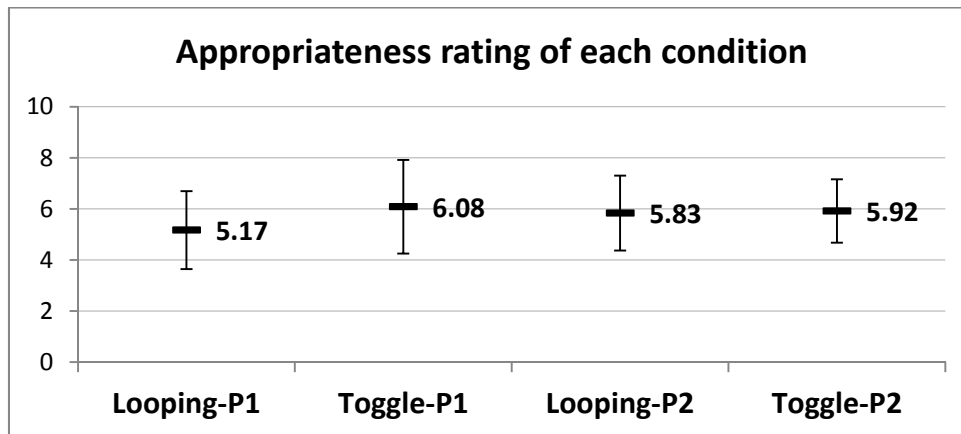


Figure 3.10. Average appropriateness rating per condition (concept-prototype), with \pm SD as error bars

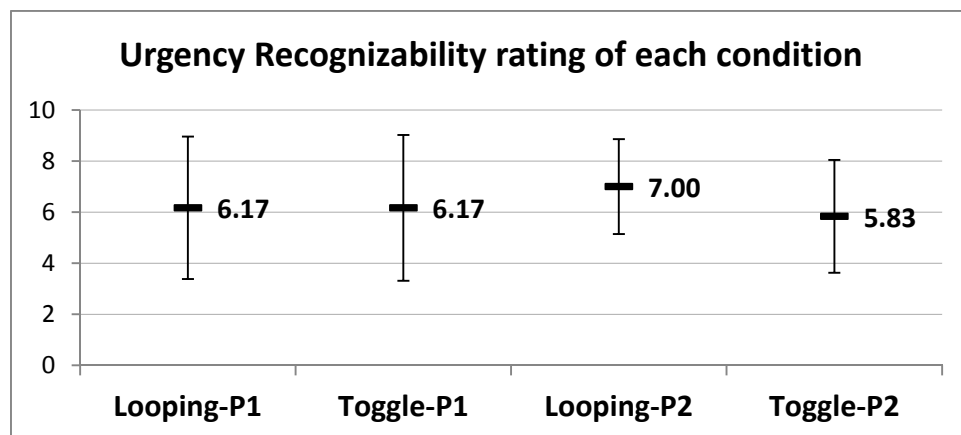


Figure 3.11. Average urgency recognizability rating per condition (concept-prototype), with \pm SD as error bars

Overall participants had no problems in learning the Slow Down and Speed Up messages. They understood the pitch direction as intended by the design, both for the 2-pulse and 3-pulse prototypes. They also recognized the different urgency levels in the signals for mapping the different urgency levels in the traffic. Only one participant was not so sure about the urgency levels in the signals because of his reliance on the traffic condition, but he assumed that “faster sounds” (shorter inter-pulse interval) means higher urgency.

Nine out of twelve participants preferred the Toggle concept over the Looping concept. For the sample size ($N=12$), Binomial test did not show significance ($p=.15$). The Toggle concept was considered less stressful and the OK signal was liked by participants. A participant said that he needed the OK signals for confirmation, because if he only heard beeps (like in the Looping concept) then he did not know whether he had to expect more coming signals or not. Similarly another participant wanted to know whether he already reached the advised speed or not. A participant commented that by using OK signals it is easier for matching with the advised speed, without having to look at the speedometer.

Among participants who preferred the Looping concept, one of them explained that it made the signal keep coming so when it was not there he knew that it was not advising speed anymore. Another participant commented that he felt like he was more free to control the signal's occurrence. The OK signals were considered too frequent and could not tell the exact target speed, so it was annoying if there were too much. One participant with the Toggle concept preference mentioned that the Looping concept was more accurate but annoying.

Ten out of twelve participants preferred Prototype 1 (2 pulses) over Prototype 2 (3 pulses) prototype. One participant could not decide for a preference, because of a learning effect (the prototypes sounded similar to each other). For the sample size ($N=12$), Binomial test did not show significance ($p=.07$). The 2-pulse prototype was considered simpler, not confusing, more easily understood due to its simplicity. Participants who preferred this prototype considered that the 3-pulse prototype was more obtrusive, annoying, and harder to understand due its complexity (2 pulses were considered clear enough).

Participants who preferred Prototype 2 (3 pulses) commented that the 3-pulse prototype was more obvious, more salient, and not ignorable. However, generally participants liked both the 2-pulse and 3-pulse signals because they thought that the pitch difference clearly indicated advices for Slow Down and Speed Up. Two participants indicated that the pitch range should be lower. Interestingly, one participant mentioned unavailability of target speed as limiting their knowledge on how fast/slow to reach the target speed.

3.3.4. Results – Objective Measurements

For an analysis of the driving behavior, we compared the effectiveness of the Looping and the Toggle concepts grouped by prototypes. The average speed response of participants was calculated separately for the Slow Down and Speed Up advices. The speed response was defined as a five second interval after a signal was given, measuring at a 2Hz frequency (every 0.5 seconds). The speed responses while using Prototype 1 (2 pulses) for the Looping and Toggle concepts are shown in Figure 3.12 (a: Slow Down, b: Speed Up). The Speed responses while using Prototype 2 (3 pulses) for the Looping and Toggle concepts are shown in Figure 3.13 (a: Slow Down, b: Speed Up).

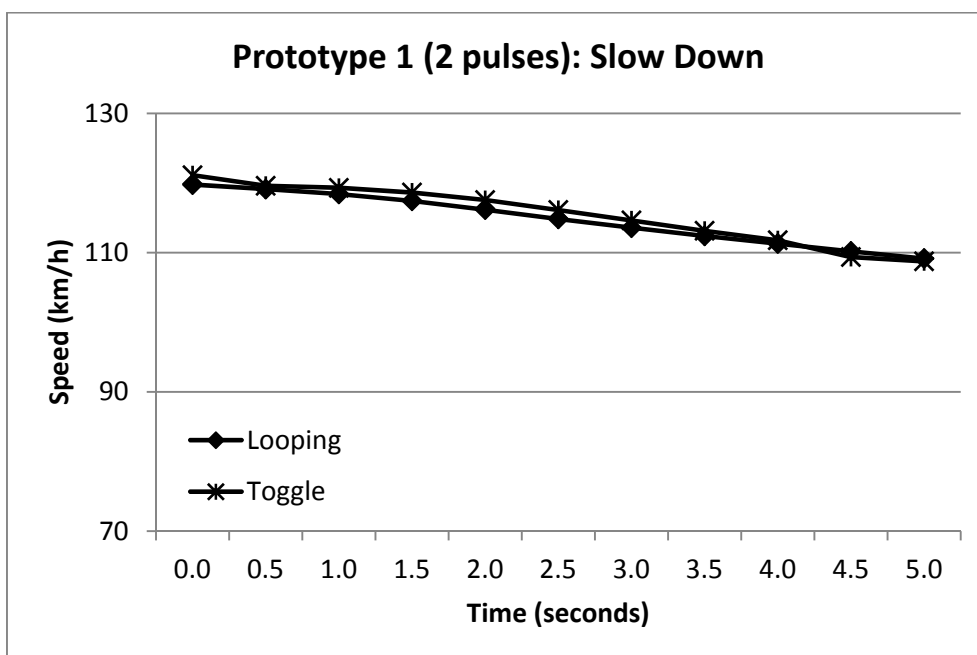


Figure 3.12.a. The average speed changes in response to Slow Down messages (Prototype 1)

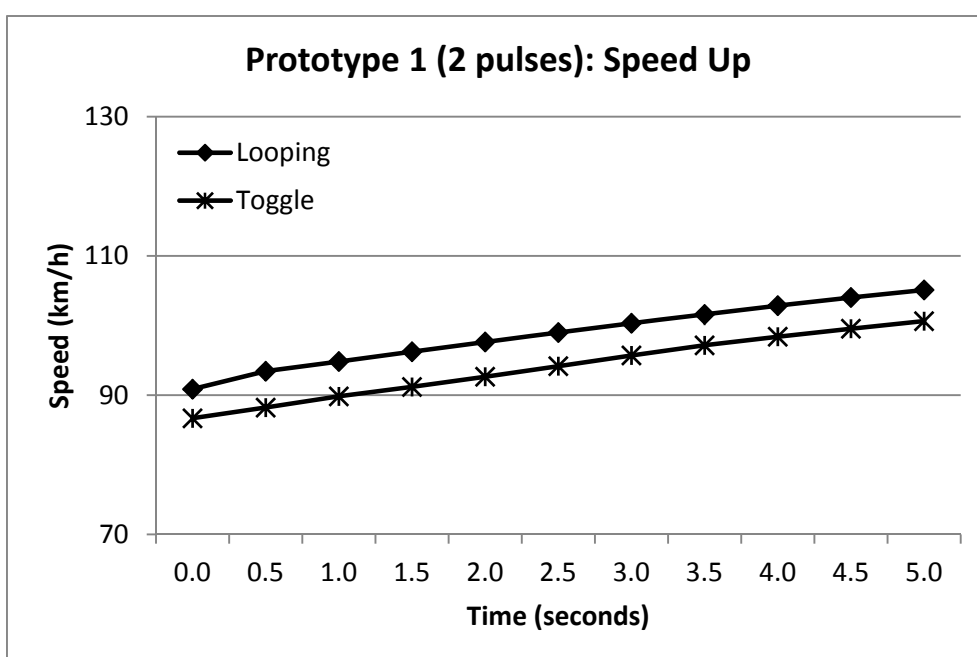


Figure 3.12.b. The average speed changes in response to Speed Up messages (Prototype 1)

The average responses to Slow Down and Speed Up messages of Prototype 1 were approximately identical between concepts. The lower start-up speed in the Speed Up graph for the Toggle concept was coincidental, but the progression of the speed on average showed a similar curve as for the Looping concept.

Using Prototype 2, the average responses to Slow Down and Speed Up messages also showed similar trends. However, the Looping concept caused slightly faster responses as represented by a steeper gradient of the curve compared to that of

Toggle concept. This effect is graphically visible both for Slow Down and Speed Up messages as shown in Figure 3.13.

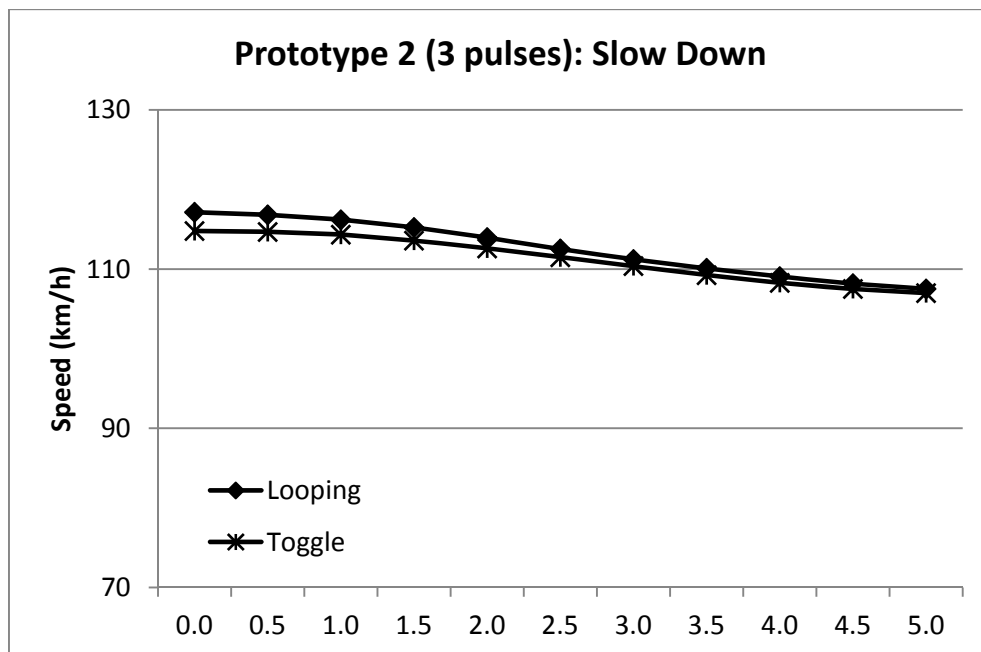


Figure 3.13.a. The average speed changes in response to Slow Down messages (Prototype 2)

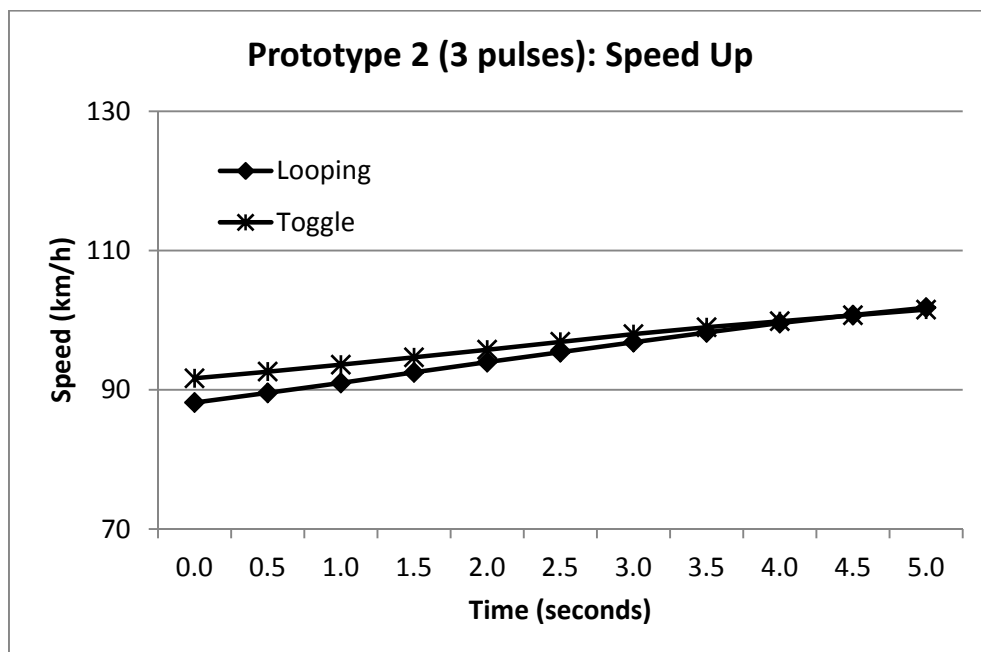


Figure 3.13.b. The average speed changes in response to Speed Up messages (Prototype 2)

3.4. Conclusion and Discussion

We propose a design for advisory auditory signals to be used by a speed assistance system, by using simple tones. The speed response data indicated that Slow Down signals caused drivers to slow down and Speed Up signals caused drivers to speed up. The analysis of the speed response data shows that both concepts were equally effective in guiding the drivers' behavior as indicated by the 2-pulse prototype, and the Looping concept seems more effective than the Toggle concept as indicated by the 3-pulse prototype.

Participants could quickly learn the auditory messages while driving, showing their understanding of the pitch direction. In addition, the signals were considered moderately high in urgency recognizability based on subjective judgment by participants. This indicates that the manipulation of the fundamental frequency of the auditory signal for coding Slow Down and Speed Up and the manipulation of the inter-pulse intervals for coding urgency were successfully applied.

The driving test results show moderately low annoyance based on subjective judgment by participants. The subjective mental effort was also considered low ("some effort"). This indicates that the use of simple tones for Slow Down / Speed Up messages in CSA is acceptable.

The Looping and Toggle concepts presented to driving test participants could be distinguished clearly by advantages and disadvantages. Most participants preferred the Toggle concept and their preference was supported by convincing arguments (less annoyance and the confirmation from OK signal).

In terms of prototype choice, we can argue that the smaller number of pulses in the 2-pulse prototype induced less annoyance as explained by participants who preferred the 2-pulse prototype. In terms of concept choice, it is difficult to make a trade-off between participant's subjective and objective data.

Regardless of participants' preferences, the 3-pulse signals may distinguish the effectiveness of the Looping concept from the Toggle concept in influencing drivers to meet speed requirements (Figure 3.13). Participants' comments on the salience of the 3-pulse signals support this difference in behavior toward speed requirements. Although more participants preferred the Toggle concept, using the 3-pulse signals it is possible that the Looping concept is used for urgent messages such as Slow Down (people tend to drive too fast), and the Toggle concept is used for less urgent messages such as Speed Up.

One point to take into consideration in judging the validity of the conclusions relates to the way the participants reacted to the different concepts. In total within 5 minutes

of driving with the Toggle concept the system displayed fewer advices ($M=13.83$) compared to driving with the Looping concept ($M=44.67$) ($t=13.07$, $df=46$, $p<.001$). This may be due to the following. In the driving test, the CSA system would not give a new advice if the most recent advice was not yet executed by the driver. With the Toggle concept, which consisted of a single auditory signal, drivers may not have noticed the advice, thus continuing to drive on the same speed. Even though the system displayed the signal again after 5 seconds if the driver did not react, the asymmetry in the number of signals remained. Furthermore, this asymmetry may also explain why the Toggle concept was considered less annoying than the Looping concept.

Overall, the effectiveness of the different concepts of CSA for improving traffic flow can be further discussed in comparison to automated systems. The advantage of advisory speed assistance system lies in its ability of engaging the driver's attention (preventing mental underload), and the disadvantage lies in the response latency affecting traffic flow from the perspective of traffic management. Another disadvantage is the lack of comfort when the advisory signals get too annoying, but this can be adjusted by filtering advices for better comfort. Given this consideration, we have shown that non-speech auditory signals can be designed that inform the driver about what to do in a timely and not-annoying manner.

4

Speed vs. Acceleration Advice

Cooperative adaptive cruise control (C-ACC) systems calculate acceleration values and exchange them between vehicles to maintain appropriate speed and headway/gap. Before C-ACC technology gets mature, cooperative driving may already be made possible by advisory systems, keeping the drivers in the loop. While C-ACC systems are based on acceleration values, in conventional vehicles one of the main sources of information to the driver for maintaining appropriate speed is the speedometer. In this chapter, we present a study addressing the question of whether advisory systems should employ acceleration or speed values to advise the driver. Subjective results show that preferences were approximately equally split between both systems. Objective results show that acceleration advice caused more uniform speed in heavy traffic and more stable distance keeping, that speed advice led to more efficient accelerator pedal changes, and that letting drivers use their preferred advice resulted in a shorter time headway/gap leading to a more effective traffic flow.⁴

⁴ This chapter is based on:

Shahab, Q., Terken, J. (2012). *Speed vs. Acceleration Advice for Advisory Cooperative Driving*. Advances in Human Aspects of Road Transportation (pp. 6001-6010). Boca Raton, USA, CRC Press.

4.1. Introduction

The algorithms of Cooperative Adaptive Cruise Control (C-ACC) calculate the acceleration/deceleration needed to optimize speed and distance. A field test demonstrated the promising effect of using an advisory C-ACC system in order to achieve better traffic flow (van den Broek et al., 2010). This field test adapted a C-ACC algorithm (van den Broek, Ploeg, & Netten, 2011) for advising drivers about the desired acceleration/deceleration in order to adjust their vehicles to the traffic.

In conventional vehicles, acceleration and deceleration are only the means by which the driver maintains appropriate speed and distance, and one of the main sources of information about speed is provided by the speedometer. In order to match the mental model of the drivers, Cooperative Speed Assistance (CSA) provides drivers with speed target information (speed advice). This raised the question whether advisory C-ACC systems should inform the driver about acceleration (as generated by C-ACC algorithms) or about desired speed.

The study described in this chapter aimed to investigate whether speed information or acceleration information is preferred by drivers and which type of advice information is more effective for traffic flow. In this chapter, we discuss the experiment setup in Section 4.2; the experiment results in Section 4.3; and discuss the results and state the conclusion in Section 4.4.

4.2. Experiment Setup

We developed two different interfaces (one for Acceleration advice and the other for Speed advice) for the purpose of the experiment. The experiment was conducted in a medium-fidelity driving simulator (Greendino, 2011).

4.2.1. System Design

Although the CSA interface gives either Acceleration or Speed advice, it also takes headway/gap into account. Headway/gap is the difference in time or space that separates two vehicles traveling the same direction. Time Headway/Gap is the time (in seconds) between the two vehicles, and Distance Headway/Gap is the space (in meters) between the two vehicles. Time headway is commonly used for safety measurement (SWOV, 2010), which is the time between the front of two vehicles. For the CSA interface we use time gap, which is the time between the rear of a vehicle and the front of a following vehicle. The interface only gives an advice whenever the driver is less than 6.5s time gap from the preceding vehicle. In other words, at 6.5s the interface tells the driver that there is a platoon ahead.

Acceleration Interface

In the Acceleration interface, a simple predictive feed-forward control algorithm is used. It takes into account acceleration, speed, and time gap values in order to create

an acceleration target of -1.0 (full brake) to 1.0 (full throttle). The acceleration advice thus guides drivers to achieve the advised time gap of the platoon, which is 1.2s based on the average time gap value obtained from a previous field trial (van den Broek et al., 2010). The following set of formulas describes the algorithm, where v_1 = driver's vehicle speed, v_2 = preceding vehicle speed, a_1 = driver's vehicle acceleration, a_2 = preceding vehicle acceleration, D = current distance between driver's vehicle and preceding vehicle in meters, and $\text{predictedD} = D$ in the next time frame.

- (1) $D_{\text{OPTIMAL}} = \text{platoonTime} * v_1$
- (2) $\text{PredictedD}_{\text{OPTIMAL}} = \text{platoonTime} * (v_1 + a_1 * dt)$
- (3) $\text{predictedD} = D + (v_2 - v_1) * dt + 0.5 * (a_2 - a_1) * dt^2$
- (4) $a_{\text{TARGET}} = (\text{predictedD} - \text{predictedD}_{\text{OPTIMAL}}) / (\text{predictedD}_{\text{OPTIMAL}})$
- (5) $dD = 0.1 * D_{\text{OPTIMAL}}$, where 0.1 is a hysteresis value
- (6) if $(D < D_{\text{OPTIMAL}} - dD)$, then ['Too Fast', shows a_{TARGET}]
- (7) else if $(D > D_{\text{OPTIMAL}} + dD)$, then ['Too Slow', shows a_{TARGET}]

The algorithm finds D_{OPTIMAL} first as the advised distance gap (in meters) based on platoon time gap and the speed of the driver's vehicle. Then it calculates $\text{predictedD}_{\text{OPTIMAL}}$, which is the D_{OPTIMAL} in the next time frame (dt = time slice). PredictedD is then calculated by taking into account the speed and acceleration of the driver's vehicle and the preceding vehicle (dt = time slice). The a_{Target} (target acceleration) is calculated based on predictedD and the $\text{predictedD}_{\text{OPTIMAL}}$. dD is the difference between D and predictedD , which is calculated with 0.1 hysteresis value so the driver is allowed 10% error in achieving the predictedD . Finally, D_{OPTIMAL} is compared with the D in order to determine the Too Slow and Too Fast conditions. The driver receives information that s/he is driving Too Slow or Too Fast and an advice on how much to accelerate or decelerate (a_{TARGET}).

Speed Interface

In the Speed interface, the system compares the driver's vehicle speed and preceding vehicle speed to provide the driver with information that s/he is driving Too Slow or Too Fast and an advice about the desired target speed. The advised time gap is taken into account, i.e. Too Slow condition is only informed when the driver maintains more than 1.2s gap, and Too Fast condition is only informed when the driver maintains less than 1.2s gap.

4.2.2. User Interface Design

Two interfaces were created, providing information about the desired acceleration and speed, respectively (see Figures 4.1 and 4.2). Both interfaces employ the same background color scheme, creating a glanceable visual display (Matthews, 2007). A black background indicates the 'Appropriate' condition, i.e. the driver is not driving too fast or too slow, or there is no platoon detected ahead (when the time gap is

larger than 6.5s). Red indicates the 'Too Fast' condition, i.e. the driver has to slow down. White indicates the 'Too Slow' condition, i.e. the driver has to speed up. The pie-like visualization shows slices to the right if the driver drives too fast, and slices to the left if the driver drives too slowly. The number of slices indicates the size of the difference between the current speed/acceleration and the target speed/acceleration. The visual design of the Acceleration interface is illustrated in Figure 4.1, and the visual design of the Speed interface is illustrated in Figure 4.2.

The CSA interface also provides an auditory distance warning, which beeps whenever the driver is too close to the preceding vehicle. It consists of a burst of two pulses with fundamental frequencies of 1600Hz each. The first pulse lasts 50ms, the second one 125ms, separated by an inter-pulse interval of 25ms. This warning sound was designed following a guideline on sound design (Edworthy et al., 1991), that high pitch and short inter-pulse interval indicate high urgency. The burst is displayed when the driver's vehicle is too close to the preceding vehicle, i.e. less than 0.5s time gap. It is displayed again after two seconds if the driver does not slow down. This two seconds interval is used, because at 0.5s there is a very high chance of collision with the preceding vehicle.

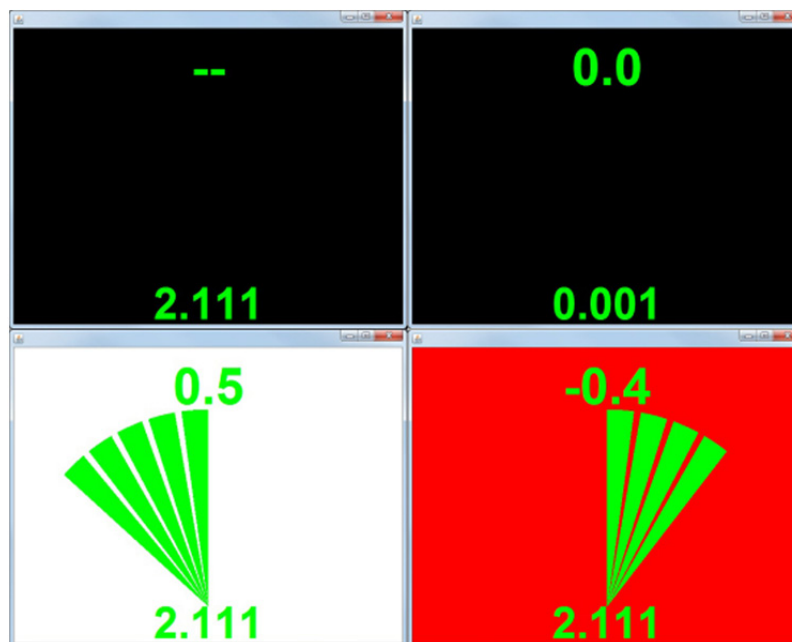


Figure 4.1. The Acceleration Interface. The number of pie slices shows the amount of acceleration i.e. 10% of full deceleration/acceleration per slice. The number above the pie ranges from -1.0 to 1.0, where -1.0 is a deceleration advice of 100% strength (full brake), and 1.0 is a full acceleration advice of 100% strength (full throttle). The bottom number shows the current acceleration in m/s^2 . The top left panel illustrates the condition of no preceding vehicle detected with current acceleration 2.111 m/s^2 , the top right panel illustrates the Appropriate condition with current acceleration 0.001 m/s^2 . The bottom left panel illustrates the Too Slow condition with a target acceleration of 0.5 (50% of full scale acceleration). The bottom right panel illustrates the Too Fast condition with a target acceleration of -0.4 (40% of full scale deceleration).

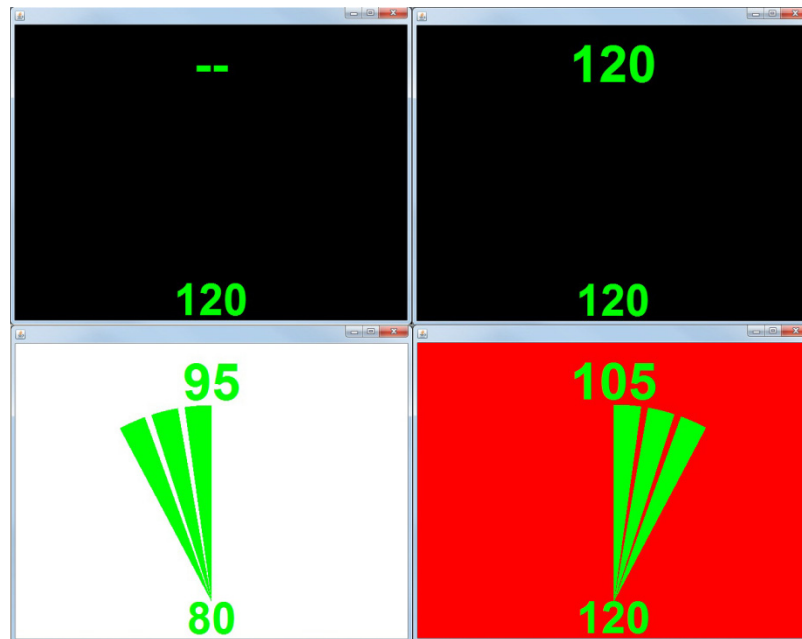


Figure 4.2. The Speed Interface. The number of pie slices shows the difference between the current speed and the target speed, i.e. 5 km/h per slice. The number above the pie shows the speed advice i.e. the speed target. The bottom number shows the current speed in km/h. The top left panel illustrates the condition of no preceding vehicle detected with current speed 120 km/h. The top right panel illustrates the Appropriate condition with current speed 120 km/h. The bottom left panel illustrates the Too Slow condition with a target speed of 95 km/h (15 km/h to increase). The bottom right panel illustrates the Too Fast condition with a target speed of 105 km/h (15 km/h to decrease).

4.2.3. Procedure

The CSA interface was developed using Java programming language showing an application of 640x480 pixel size displayed on a 7-inch screen. The application was connected to the driving simulator in order to exchange real-time network messages every 50ms. The network message consists of speed, acceleration, time headway, preceding vehicle's speed and acceleration, brake, and throttle pedal values.

For the simulations we developed two highway scenarios: one with an Easy platoon (small fluctuations of the platoon's speed) and one with a more demanding (Hard) platoon (large fluctuations of the platoon's speed). The Easy platoon had a random fluctuation between 100 and 110km/h, and the Hard platoon had a predefined fluctuation of 120 km/h, 60 km/h, 105 km/h, 60 km/h, 105 km/h, which was adapted from the speed profile used in the field trial mentioned previously (van den Broek et al., 2010).

Twenty nine drivers (7 female, 22 male, age 20-38) with minimum 1.5 years driving experience participated in the experiments. After some practice driving (up to 5 minutes) to get used to the simulator, the participants were required to drive with one interface first, and another interface later. Order of interfaces was balanced across participants, i.e. half of the participants drove with the Acceleration interface

first, and the other half with the Speed interface first. For each interface, they first drove in the Easy platoon and then in the Hard platoon. They were asked to follow a platoon with the assistance of the interface. In the beginning of each interface usage, they received an explanation about the interface in order to learn how it worked. In total, each participant drove four 7-9 minute periods (depending on their preferred speed and the traffic condition).

After each period of driving, each participant rated their subjective mental effort based on the Rating Scale Mental Effort (RSME) (Zijlstra & van Doorn, 1985) of 0 (absolutely no effort) to 150 (more than extreme effort) as described in Appendix B.2. After each usage of the interface, each participant rated the interface using the Van Der Laan acceptance scale (Van Der Laan, Heino, & De Waard, 1997). The scale consists of nine 5-point Likert scales: Useful-Useless, Pleasant-Unpleasant, Good-Bad, Nice-Annoying, Effective-Superfluous, Likeable-Irritating, Assisting-Worthless, Desirable-Undesirable, Raising alertness-Sleep inducing (see Appendix C.1 for details).

At the end of the experiment, participants were interviewed in order to obtain a preference of interface and discuss the reasons and the difference between the interfaces. Participants received a small fee based on 40 minute participation.

4.3. Experiment Results

4.3.1. Subjective Results

Based on the RSME results, the Acceleration (Ac) interface was rated as requiring more mental effort than the Speed (Sp) interface. Multivariate tests show an effect of Interface ($F_{1,28} = 5.591$, $p = .025$), no Platoon effect, and no interaction effect between Interface and Platoon. Both in the Easy and Hard platoons, Ac was more demanding than Sp (mean for Ac = 48.64, for Sp = 39.47 out of 150).

Based on the Van Der Laan scale ratings, generally all participants regarded both interfaces as somewhat unlikely to induce sleep (Ac: $M=2.00$, $SD=0.93$ and Sp: $M=2.21$, $SD=0.90$ out of 5.0 scale). Multivariate tests of each Van Der Laan item \times Preference show an interaction effect, except for Good-Bad and Likeable-Irritating. The interaction effect (as in Table 4.2) shows that the preferred interface received higher rating than the other interface for the positive items, and the preferred interface received lower rating than the other interface for the negative items. This effect is illustrated graphically in Figure 4.3 (a&b).

Table 4.2. Acceptance scores (5 points) as a function of preference

Item	Ac preference		Sp preference		Interaction effect
	Ac	Sp	Ac	Sp	
Useful	4.36	3.55	3.72	4.06	$F_{1,27}=5.131, p=.032$
Effective	4.18	3.45	3.78	4.17	$F_{1,27}=7.54, p=.011$
Assisting	4.27	3.73	3.89	4.28	$F_{1,27}=5.959, p=.021$
Desirable	3.45	3.36	3.11	3.94	$F_{1,27}=4.713, p=.039$
Unpleasant	2.09	2.73	3.11	2.11	$F_{1,27}=10.168, p=.004$
Annoying	2.18	2.73	3.00	2.17	$F_{1,27}=6.841, p=.014$
Good	4.09	3.91	3.56	3.94	$F_{1,27}=2.007, p=.168$
Irritating	2.64	2.73	2.72	2.22	$F_{1,27}=2.75, p=.109$

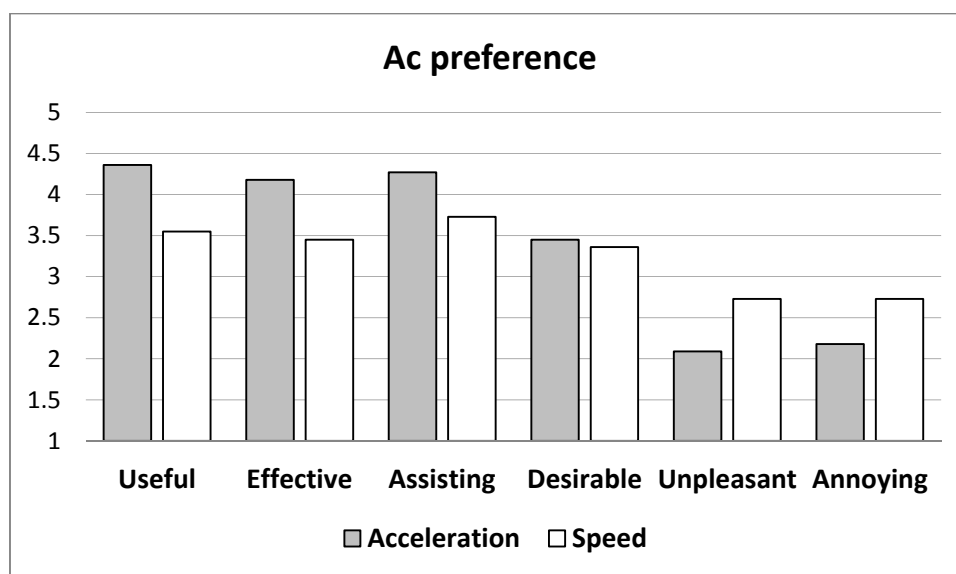


Figure 4.3.a. The preferred interface (Acceleration, gray bars) received higher ratings on positive items (useful, effective, assisting, desirable) and lower ratings on negative items (unpleasant, annoying).

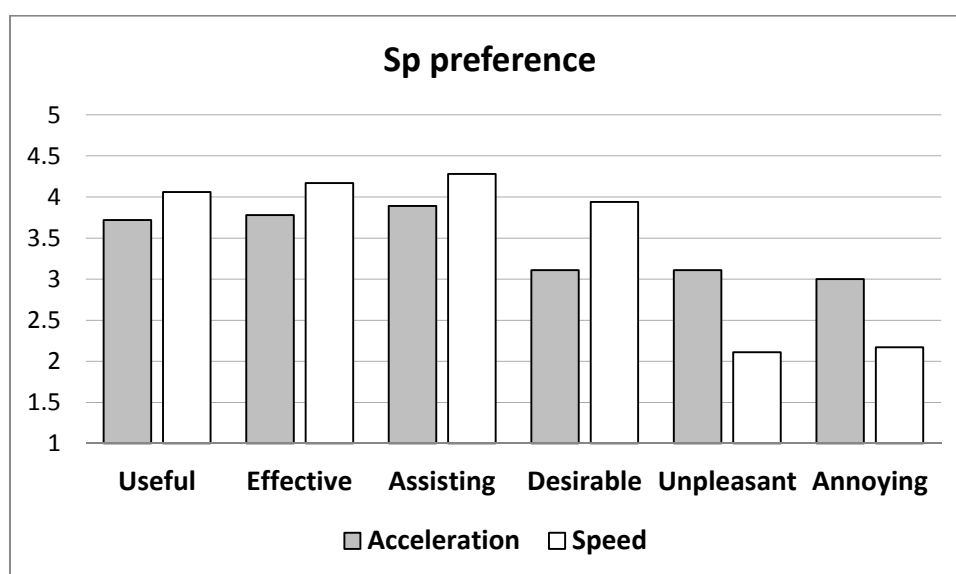


Figure 4.3.b. The preferred interface (Speed, white bars) received higher ratings on positive items (useful, effective, assisting, desirable) and lower ratings on negative items (unpleasant, annoying).

The interview results show that 18 participants preferred the Speed interface and 11 participants preferred the Acceleration interface. Participants preferring the Speed interface indicated that they considered it to be calmer, create less panic, and offer more freedom to control the vehicle, and that the rate of change of the information was lower than in the Acceleration interface. Participants preferring the Acceleration interface indicated that they considered the information to be more precise and the Speed interface to be less safe.

Participants also commented about the colors, pie-like visualization and the numbers on the interface. They mostly liked the color changes for the noticeability. They mostly agreed that the current acceleration information was meaningless compared to the current speed information. The target speed number was considered useful by those who preferred the Speed interface, and the graphical acceleration information was considered useful by those who preferred the Acceleration interface. Even though the preciseness (10% per pie slice) of the pie-like visualization was considered quite helpful, participants could not estimate the exact amount of acceleration required by the system, and they mentioned that some practice would be needed to get used to it.

4.3.2. Objective Results

4.3.2.1. Speed

Analysis of Variance indicated that the average speed was smaller in the Easy platoons than in the Hard platoons ($F_{1,28}=2367.72$, $p<.001$). The average speed in the Easy platoons was 101.42 km/h, and in the Hard platoons was 82.2 km/h. This difference was expected, because this is a result of the speed profiles used in the platoons. There was an Interface \times Platoon interaction ($F_{1,28}=8.732$, $p=.006$), showing that in the Hard platoons the average speed was higher using the Speed interface ($M=83.06$ km/h) compared to using the Acceleration interface ($M=81.34$ km/h), as illustrated in Figure 4.4.

The higher average speed in the Hard platoon for the Speed interface may be due to more overshoot (less precision) compared to using the Acceleration interface, resulting in a need to decelerate again. In order to remove this overshoot effect, the higher frequency data (high fluctuation of speed) were removed using frequency domain analysis (data of one participant had to be removed due to insufficient data for the computation). The difference between interface conditions in the Hard platoons still applied ($t=-9.377$, $df=27$, $p<.001$), i.e. higher average speed using the Speed interface ($M=82.96$ km/h) compared to using the Acceleration interface ($M=81.05$ km/h).

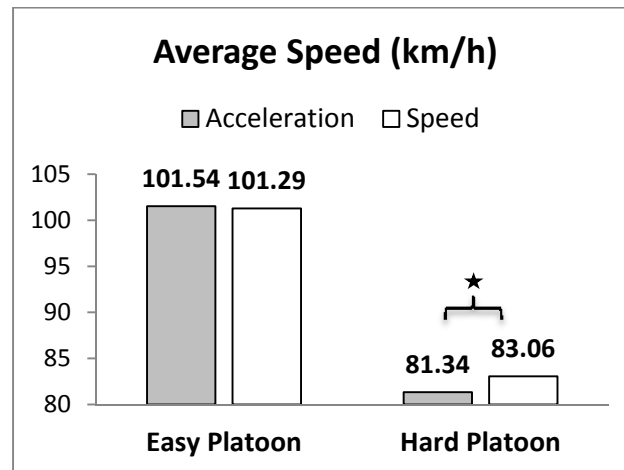


Figure 4.4. Comparison of the average speed taken between using Acceleration interface and using Speed interface, in the Easy platoon (no difference) and in the Hard platoon (statistically different).

Multivariate analysis of variance indicated that there was also an interaction effect between Interface and Preference ($F_{1,27}=7.048$, $p=.013$). Participants who preferred the Acceleration interface did not drive differently using Acceleration and Speed interfaces, but participants who preferred the Speed interface drove faster ($t=-2.887$, $df=27$, $p=.008$) while using the Speed interface ($M=92.73$ km/h) than while using the Acceleration interface ($M=91.17$ km/h).

The standard deviation of the speed was also different between platoons, because the platoons were different as intended, i.e. there were more fluctuations of speed in the Hard platoon than in the Easy platoon ($F_{1,28}=576.75$, $p<.001$). There was an interaction effect between Interface and Platoon ($F_{1,28}=10.46$, $p=.003$), showing that in the Hard platoons the average standard deviation was higher when using the Speed interface ($M=16.15$ km/h) than when using the Acceleration interface ($M=14.91$ km/h). The average standard deviation was lower in Easy platoons ($M=5.71$ km/h), with no differences between interfaces (details in Figure 4.5).

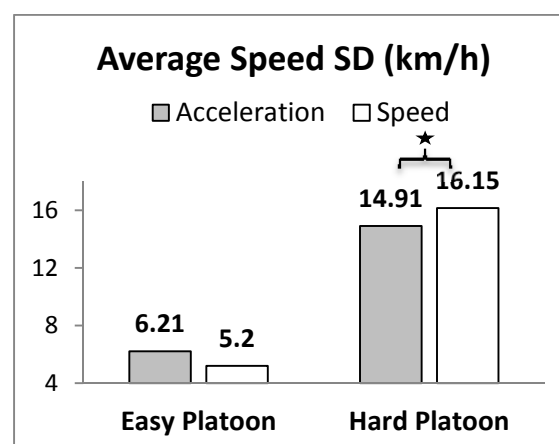


Figure 4.5. Comparison of the average standard deviation of speed taken between using Acceleration interface and using Speed interface, in the Easy platoon (no difference) and in the Hard platoon (statistically different).

4.3.2.2. Time Gap

Apart from variation of speed, distance between vehicles also provides information about the stability of a platoon. Time headway/gap is a preferred measure for distance to preceding vehicle, because distance in meters varies depending on the vehicle's speed. Thus, time headway/gap provides more consistent information. Although the advised time gap was 1.2s, the average time gap maintained by participants throughout the experiment was larger than 1.2s. Participants maintained 1.41s average time gap with no effect of platoons and interfaces.

However, multivariate analysis of variance shows that there was an interaction effect between interfaces and participant's preference for Ac interface or Sp interface ($F_{1,27}=4.894$, $p=.036$). Participants who preferred the Acceleration interface maintained a shorter time gap while driving using the Acceleration interface ($M=1.44s$) compared to driving with the Speed interface ($M=1.62s$). Participants who preferred the Speed interface maintained a shorter time gap while driving using the Speed interface ($M=1.28s$) compared to driving with the Acceleration interface ($M=1.39s$). This shows that they maintained shorter time gap with their preferred interface, as seen in Figure 4.6.

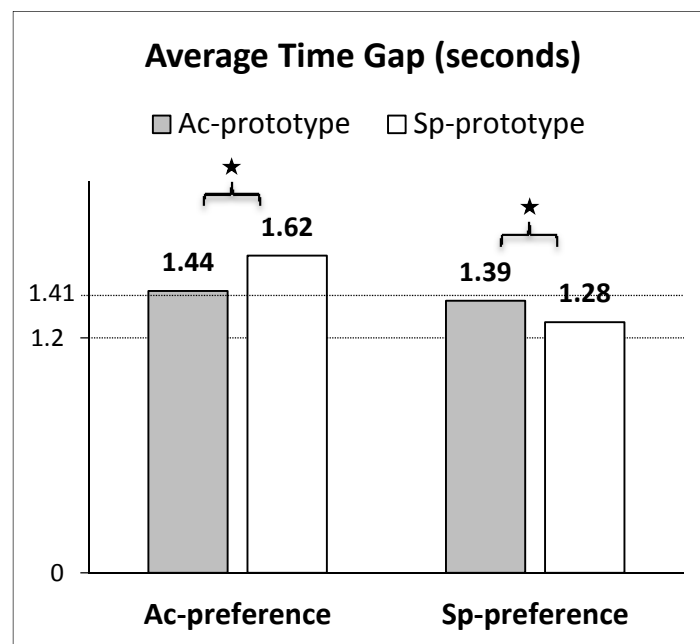


Figure 4.6. The interaction effect between preference and average time gap. Those with Ac preference maintained shorter time gap while driving with Ac prototype, and those with Sp preference maintained shorter time gap while driving with Sp prototype. The line at 1.2s is the advised time gap. The line at 1.41 is the average time gap across all conditions.

Standard deviation of time gap was measured in order to find out the precision in distance keeping. Both in Easy and Hard platoons, average standard deviation of time gap was smaller ($F_{1,28}=12.43$, $p=.001$) while driving using the Acceleration interface (mean deviation = 0.65s) compared to driving with the Speed interface (mean deviation = 0.78s).

4.3.2.3. Accelerator Pedal Analysis

Measurement of accelerator pedal movements provides information about the efficiency of throttle changes i.e. both deeper and more frequent changes are considered less efficient. In the experiment, the recorded throttle data consisted of values ranging from 0 (no pressure on the acceleration pedal) to 1.0 (full pressure on the acceleration pedal). In order to analyze the frequency of the throttle changes, a Fast Fourier Transform (FFT) was applied for frequency domain analysis. The output was a plot of frequencies against amplitude (components of throttle depth) of each frequency.

Multivariate tests were done on the range of 0.0-0.1 Hz, because those frequency data have visible peaks on the FFT plot, as seen in Figure 4.7 below. The frequency of 0.1 Hz means a change of throttle value every 10 seconds. Based on Multivariate tests, using the Acceleration interface resulted in larger throttle changes compared to using the Speed interface, both in Easy and Hard platoons ($F_{1,25}=9.637$, $p=.005$). There was an interaction effect between Interface and Platoon ($F_{1,25}=5.255$, $p=.031$), indicating that the difference in the throttle changes was larger in Hard platoons ($t=3.034$, $df=25$, $p=.006$) than in Easy platoons ($t=2.128$, $df=25$, $p=.043$).

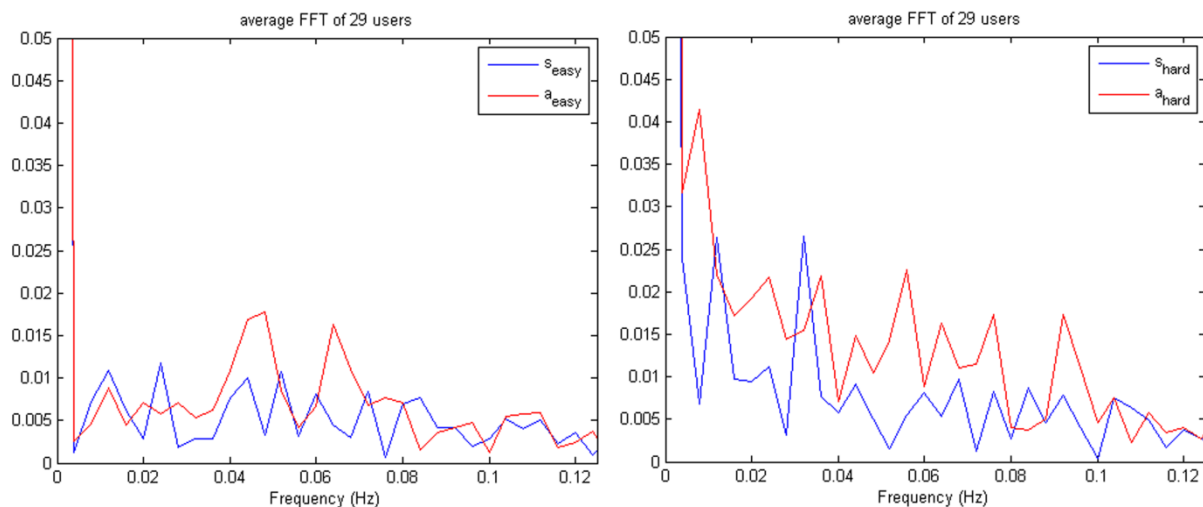


Figure 4.7. The 5000-point FFT computation of throttle data of each user averaged and plotted. X-axis shows the frequencies (0 to 0.12 Hz), Y-axis shows the amplitude (components of throttle depth). The left image shows the data from the Easy platoon, and the right image shows the data from the Hard platoon. The red line represents the Acceleration interface, and the blue line represents the Speed interface. It is visible that the red line has higher peaks than the blue line.

4.4. Conclusion and Discussion

We conducted an experiment for the purpose of cooperative driving to investigate subjective judgments and performance effects of acceleration and speed advice in easy and hard traffic conditions. We found that acceleration advice leads to more mental effort, as rated by the participants. This is supported by the average speed

data, showing that participants maintained lower speed with the acceleration advice while driving in Hard platoons (Figure 4.4).

The acceleration advice resulted in a more uniform speed among drivers in the case of hard traffic condition, shown by the lower standard deviation in speed compared to driving with the speed advice (Figure 4.5). Moreover, the standard deviation in time gap was also lower compared to driving with the speed advice regardless of traffic condition. These findings show that acceleration advice may lead to fewer shockwaves due to less deviation in speed and time gap. However, driving with the acceleration advice required larger changes of the throttle pedal, both in easy and hard traffic condition (Figure 4.7). This indicates that drivers have problems in adjusting their speed precisely according to the acceleration advice. As deeper throttle leads to more fuel consumption, this means that acceleration advice may also lead to less efficient fuel consumption.

There was no clear preference for one type of advice, so we concluded that there are different types of drivers: those who prefer acceleration advice, allowing more precise control, and those who like speed advice, allowing more freedom in the implementation of the advice. From the objective data, the smaller standard deviation of time gap using the Acceleration interface indicates precision, and the higher standard deviation of time gap using the Speed interface indicates freedom. This is further supported by the fact that the participants who preferred the Speed interface drove faster in both types of platoons while using the Speed interface.

Interestingly, the average time gap was shorter when people drove using their preferred interfaces. Since shorter time headway/gap is useful for better traffic throughput (van Arem et al., 2006), we argue that the usage of the preferred interface may result in better traffic throughput. Practically this may be made possible by allowing drivers to choose between acceleration and speed advice in such an assistance system. This suggestion to let drivers have their preferred interface is also supported by the positive Van Der Laan results for the preferred interface (Figure 4.3).

In conclusion, both types of advice have their own advantages and disadvantages. While the speed advice takes less mental effort and more efficient acceleration pedal changes, the acceleration advice is more useful for reducing the likelihood of traffic shockwaves. Looking at the differences among people, we argue that people can adapt to their preferred advice and have more confidence in driving with a shorter headway/gap.

5

The CSA Prototype

This chapter presents the development of a multimodal interface for Cooperative Speed Assistance (CSA) and discusses how it can be combined with existing systems such as navigational systems, and personalized according to driver's profiles. Results from three driving simulator experiments in Chapters 2, 3, 4 are summarized and used as a foundation to the final user interface design. This chapter concludes with a recommendation for the user interface design of a portable in-vehicle system.

5.1. Introduction

Cooperative driving will only create beneficial effects to the traffic throughput if Cooperative Speed Assistance (CSA) is sufficiently dispersed among road users. In order to lower the threshold to adopt cooperative driving, CSA is designed for easy retrofit to any vehicles. Therefore, CSA is developed as a nomadic device, with a possibility of integration with existing nomadic systems such as Portable Navigation Devices (PND) and navigation applications in smartphones.

Since nomadic devices cannot easily be connected to tactile or haptic interfaces in the vehicle, we focus on using visual and auditory modalities for information presentation. This direction still leaves a lot of room for design. What kind of information should be presented to drivers? Which interface modality should be used in presenting which information? What does the screen look like?

In this chapter, results from previous studies (Chapters 2, 3, 4) are discussed and used as a basis to finalize the design of the CSA prototype. It takes into account the restrictions of a nomadic device and the user preferences obtained in previous studies. Section 5.2 explains the different types of information needed by drivers in order to engage in cooperative driving and Section 5.3 explains the applicable modalities of information presentation through a nomadic device. In other words, Section 5.2 is about What to present in the interface, and Section 5.3 is about How we present this information. Section 5.4 describes the final design for the CSA user interface while taking into account the results from the three previous studies. Section 5 presents the conclusions and the next step.

5.2. Contents of Information

In this section, we describe the types of information to be presented to drivers.

5.2.1. *Advice Only vs. Extra Information*

The first exploratory study on CSA design (Chapter 2) was conducted by developing an interface providing visual and auditory information and evaluating the interface in a driving simulator. This driving simulator test was preceded by two focus group discussions in order to find which types of information drivers expected from a CSA device. Participants considered information about traffic jams, unavailable roads, traffic density, environment (speed limit, safety level, traffic regulation, etc) to be important. Also, participants wanted to know the reasons for the system's advice.

Two prototypes were developed: Guidance (advice only) and Explanation (extra information). They both informed users about speed choice in three states {Too Slow, Appropriate, Too Fast}. In the Guidance prototype, users were only presented with advice. In the Explanation prototype, in addition to advice, users were presented

with extra information (explanation or consequences of following the advice). Twenty four drivers participated in this driving simulator test.

After driving with both prototypes, participants were asked to make a forced preference between prototypes. Nine participants preferred the Guidance prototype because of its subtlety. Fifteen participants preferred the Explanation prototype, because they liked the extra information for triggering action and sensing high urgency (subjective perception). With respect to the extra information, participants mentioned general safety warning and traffic jams as the most important ones (see Section 2.5.2).

We did not use the preference result (15 vs. 9) to conclude that we should focus on the Explanation Prototype only. Instead, we took the results to indicate that a one-size-fits-all interface is not applicable.

5.2.2. Speed vs. Acceleration Advice

A driving simulator experiment (Chapter 4) was conducted in order to determine what kind of information is more useful to act as an advice to drivers. The background of this experiment is a field test of cooperative driving where a C-ACC algorithm was adapted for an advisory system. While C-ACC-based advice uses acceleration information, in conventional vehicles drivers receive speed information from the speedometer. Therefore, it is important to find out which information let drivers perform better.

Two prototypes were developed: Acceleration advice and Speed advice. The interfaces consisted of visual information only. At the end, participants were interviewed, and asked to make a forced preference between the two prototypes. Eighteen participants preferred speed advice, because it allowed freedom in the execution of the advice. Eleven participants preferred acceleration advice, because they found it more helpful in keeping proper distance. Indeed, it was found that driving with acceleration advice resulted in a smaller variance in distance gap compared to driving with speed advice. Further analysis of the objective data showed that driving with the preferred advice let drivers keep a closer distance to the platoon. This is considered a better performance in terms of more efficient traffic throughput.

We did not use the preference result (18 vs. 11) to conclude that we should focus on implementing the speed advice only. Instead, we took the results to indicate that a one-size-fits-all interface is not applicable.

5.3. Multimodal Presentation of Information

In this section, we present how to map information from the previous section onto visual and auditory modalities.

5.3.1. Visual Modality

A literature study by Ho & Spence (2008) shows that the visual modality is not suitable for driver-vehicle interaction while driving. The driving task takes most of the visual attention, thus drivers are prone to inattention to the information provided by the interface. However, the visual system can be divided into focal and ambient processing, as indicated by a literature review (Horrey, 2009). While focal vision is already burdened by the task of driving, the ambient presentation of information involves peripheral vision, and is mostly sensitive to motion and spatial orientation. The peripheral vision is sensitive for changes in motion, but not sensitive for driving in limited visual conditions such as night time.

Driving is a multitasking activity. Like other multitasking activities, the human performer focuses on one task and switches tasks when required. While driving, a driver may use glances to switch from looking at the road to looking at in-vehicle visual displays. In this case, the driver switches from peripheral vision to focal vision to look at the in-vehicle displays. It is important that drivers can keep using peripheral vision to interact with in-vehicle visual displays, so glances are minimized.

The aspect of peripheral vision was explored in the experiment in Chapter 2. The main design element of both prototypes in the driving simulator test of Chapter 2 was the color changes on the whole background of the application screen. The states (Too Slow, Appropriate, Too Fast) were represented by white, black, red colors respectively. Although the prototype also employed auditory signals to display the same information (Too Slow, Appropriate, Too Fast), the test participants judged the color changes as more action triggering than the auditory signals.

In Chapter 4, the aspect of peripheral vision was explored again. The same color coding (white, black, red) was used for indicating the three states (Too Slow, Appropriate, Too Fast). Most participants of this experiment liked the color changes for the noticeability. In both experiments, participants did not indicate annoyance on the color changes yet they indicated that the colors were alerting enough. Therefore, this color coding is kept for the final prototype design.

5.3.2. Auditory Modality

The prototypes used in the exploratory study (Chapter 2) employed both visual and auditory modalities for presenting the same information (Too Slow, Too Fast). The redundant presentation of advice allowed test participants to compare which information modality was more useful. The auditory interface received neutral ("So-

so”) ratings on usefulness, and lower ratings than the visual interface on usefulness and pleasantness from the participants (see Figures 2.10-2.12 on page 39-40). Moreover, it was judged as less action triggering than the visual interface by the participants.

The study in Chapter 3 was conducted in order to redesign the auditory signals used in Chapter 2 and also to study the use of auditory signals as the only means of presentation (no redundancy). Therefore, the driving simulator test was conducted with an auditory only interface. Two concepts (Looping and Toggle) and two prototypes (2 pulses in a burst and 3 pulses in a burst) were tested in a 2x2 experiment design. In the Looping concept, the signal is displayed repetitively until the user complies with the advice. In the Toggle concept, the signal is displayed once and when the user complies with the advice an “OK” signal is displayed.

The driving test results show moderately low annoyance and moderately high urgency recognizability based on subjective judgment by users. The subjective mental effort was also considered low (“some effort”). There was no difference between Toggle and Looping and between 2-pulse and 3-pulse in terms of mental effort.

The majority of test participants (10 out of 12) preferred the 2-pulse prototype over the 3-pulse prototype, because it was considered as less annoying, simpler, and easier to understand. Based on these reasons, we decided to keep the 2-pulse prototype for the final prototype design.

Based on analysis of the objective data, compliance with the advice appeared to be similar for both concepts. The majority of test participants (9 out of 12) preferred the Toggle concept because it was judged as less stressful and the OK signal was useful. In Section 3.5, it is discussed that this was possibly related to the asymmetry in the number of signals displayed. The Looping advice kept repeating until participants complied with the advice. Therefore, the Looping advice might be less annoying if it would be displayed only intermittently.

5.4. The User Interface Design

Learning from the three studies, we decided that the final prototype should provide speed advice (Too Slow, Appropriate, Too Fast) and extra information in the form of a glanceable visual display. We decided that the final prototype should present information to users both through the auditory (2-pulse prototype) and visual (of three distinct background colors: white, black, red) modalities.

Thus our proposal is to combine two interface modalities: visual and auditory. Learning from the study in Chapter 3 where auditory information was successfully used to advise drivers to speed up / slow down, the auditory interface is proposed to convey different information from that conveyed by the visual interface. Instead of redundancy, this multimodal information presentation mode is called concurrency (Nigay, 2004), where two modalities present different information at the same time.

Since the visual interface provides speed information, we decided to use the auditory interface to present distance keeping advice. This is based on the finding in Chapter 4 that the distance keeping precision was regarded positively by participants who preferred the acceleration interface. The Too Slow – Too Fast signals are directly translatable to Too Far – Too Near distances. Using the Toggle concept might interfere with the speed advice due to its OK signal, thus we decided to use the Looping concept. In order to reduce the annoyance, we set the signal to be displayed only if drivers need the advice. For example, with a 1.2s advised time gap, there will be no auditory signals for ‘Too Near’ if the driver is already too slow at 1.0s. Similarly, there will be no auditory signals for ‘Too Far’ if the driver is already too fast at 1.4s as a result of changing speed limits.

The auditory interface from the study of Chapter 3 was recoded, while keeping the pulse length the same (100ms). As in Section 3.3.1, the inter-pulse intervals were dependent on the advice (in this case: time gap advice). For the Too Near condition, the minimum is 10ms (at 1.19s time gap) and the maximum is 690ms (at 0.51s time gap). For the Too Far condition, the minimum is 10ms (at 1.21s time gap) and the maximum is 1990ms (at 3.19s time gap). From 3.2s time gap and farther, there is no distance advice.

Taking into account the combination of CSA with a PND, we designed a simple visual interface for navigation (as in Figure 5.3). As commonly used by existing PND products, a speech message was also designed for each turning advice (“turn right!” and “keep straight!”) using a Text-to-Speech engine (Acapela Group, 2009).

As mentioned in Section 5.3.1, we need to fix the visual information of the speed advice. As seen in Figure 2.3, the locations of current speed and target speed were not consistent. Therefore, we decided to arrange the current speed and target speed vertically, instead of horizontally, with the target speed always on top. This consistency principle is adopted from principles of display design (Wickens et al., 2004). The final design for Too Slow and Too Fast states is illustrated in Figure 5.3.

The white-black-red colors indicating the {Too Slow, Appropriate, Too Fast} states can no longer take the whole application background, because of the combination with navigational application screen. To keep the three-state information in the

driver's peripheral vision while driving, the color codes are shown at the perimeter of the screen. This design is similar to the change border concept by Matthews, Czerwinski, Robertson, & Tan (2006) for improving multitasking efficiency.

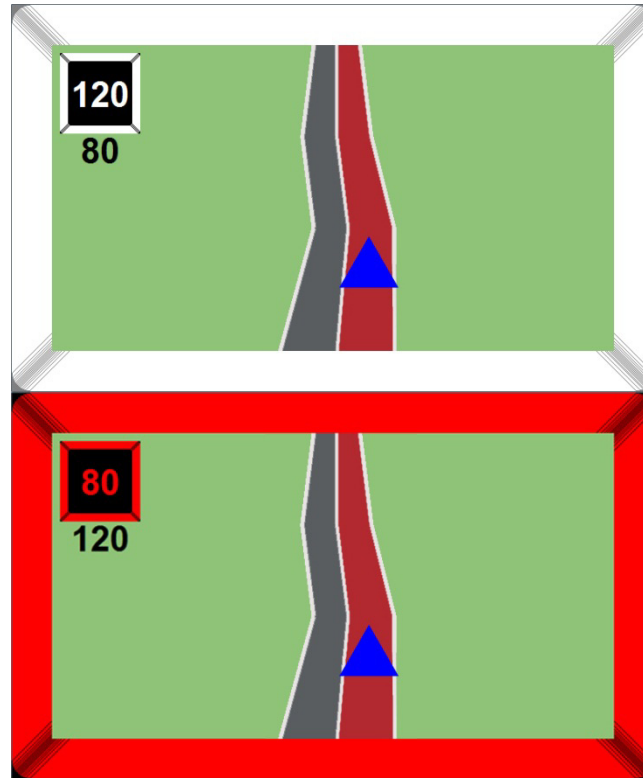


Figure 5.3. Above: Too Slow advice; Bottom: Too Fast advice.

After combining CSA and PND applications, the acceleration advice can no longer be displayed visually. It is replaced by the auditory distance advice as mentioned above. There is still a large screen space available for providing extra information, which is the right-top area. The extra information as mentioned in Section 5.2.1 can be displayed on this space.

A relevant issue with the visual modality of information presentation in a nomadic system is the location of the visual display. A study comparing head up displays (overlaid on the visual horizon), head-down displays (located near the mid-console), and adjacent displays (just above the vehicle hood) reported that adjacent displays best supported driver performance (Horrey & Wickens, 2004). This study supports an argument for attaching the CSA device as close as possible to the bottom of the vehicle windscreen. Figure 5.4 shows the location of CSA device to be used in the next driving simulator experiment.



Figure 5.4. Location of CSA as attached to the driving simulator.

5.5. Conclusion and Next Step

Three driving simulator experiments have generated insights for the purpose of deciding a design for the user interface of portable in-vehicle systems. The insights led to recommendations for deploying portable in-vehicle systems with limited user interface modalities, and porting such systems to different nomadic devices including smartphones. The recommendations are: 1) Use color-based glanceable displays to allow drivers use peripheral vision; 2) Use simple tones for displaying non-redundant alerting information; 3) Allow personalization based on user preferences and driving behaviors.

Personalization is not new for automotive systems, as exemplified by a study on in-car infotainment systems (Garzon, 2012). Moreover, it has been shown that drivers do exhibit different behaviors (Stradling, 2007). If CSA takes into account the different behaviors, it may further lower the threshold for adopting the appropriate behavior for performing cooperative driving. In other words, how can we persuade drivers to comply with the advice from CSA?

The next chapters explain the follow-up studies. Chapter 6 decides the persuasion concept to be deployed into CSA as a behavior change support system. Chapter 7 outlines the method for identifying the behavioral differences among drivers. Chapter 8 describes the evaluation of CSA as a behavior change support system.

6

Supporting Behavior Change in Cooperative Driving

For applying proper acceleration/speed/distance, drivers need to have the ability, the opportunity and the motivation to do so. The CSA system already supports the ability and the opportunity needed to perform the advised actions, but it does not yet support motivation. This chapter focuses on ways to support motivation and how supporting motivation can lead to a sustainable behavior change. Given that there are individual differences in motivation, we propose persuasion by taking into account personal values for motivating people to participate in cooperative driving. In this chapter, the development of a concept applying Persuasive Technology for CSA is described. The requirements for a CSA system are explained and related to the existing literature. We then review the persuasion literature that is relevant for sustainable behavior and deals with different ways to support motivation. Literature on personal values in driving was also studied and presented in relation to the driver's attitude and behavior. This chapter concludes by outlining the next step to identify the different ways to support motivation for drivers.⁵

⁵ This chapter is based on:

Shahab, Q. (2012). *Supporting Behavior Change in Cooperative Driving*. Constructing Ambient Intelligence, Communications in Computer and Information Science 277 (pp. 323-327). Springer Berlin Heidelberg.

Shahab, Q., Terken, J., Eggen, B. (2013). *Development of a Questionnaire for Identifying Driver's Personal Values in Driving*. Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp.202-208). Eindhoven, Netherlands, ACM Press.

6.1. Introduction

A large-scale survey with 7687 European drivers (CVIS Project, 2007) reported user acceptance of ITS applications. The top five desired messages were: Warning about Ghost Drivers, Warning message 5km ahead of accident, Current traffic flow, Speed limits, Messages to speed up / slow down to regulate traffic flow. All of these messages (except Ghost Drivers) are applicable in regular highway traffic, where traffic jams are among the problems that disturb traffic flow most. The results of this survey suggest that cooperative driving may be accepted by users. However, it will still take a while before automated forms of cooperative driving are available. Therefore, Cooperative Speed Assistance (CSA) might be an intermediary step to achieve the benefits of cooperative driving.

The physical design of CSA aims for easy retrofit to any vehicle. Therefore, CSA is developed as a portable device, with a possibility of integration with existing portable systems such as Portable Navigation Device (PND). It is assumed that a portable system lowers the threshold to adopt cooperative driving in the near future.

For people to adopt the technology, they need to have the motivation, the ability, and the opportunity to do so. Therefore, to persuade drivers, CSA has to support all the three determinants. Drivers need to have the motivation, the ability, and the opportunity for applying proper acceleration/speed/distance i.e. complying with CSA advice as appropriately as possible during their trips.

Motivation is associated with the driver's personal decision to follow an advice or not. Ability refers to the driver's ability to change speeds according to the advice. It is supported by the driver's cognitive and physical abilities in understanding and applying the right speed. Opportunity refers to the right moment to adjust the speed in relation to the vehicle's situation among other vehicles in the traffic. The opportunity information is supported by the V2X (vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-everything communications) technology.

So far, the CSA concept provides ability support by giving advice on how much a driver needs to adjust his/her speed and provides opportunity support by presenting the personalized information at the right moments. This design can overcome the lack of opportunity support in existing systems such as the dynamic speed advice displayed on signs above highways. However, the fact that drivers tend to neglect the dynamic speed advice also reveals a lack of motivation. This lack of motivation may be caused by personality, but it may also be caused by the lack of knowledge about the need and the benefits of complying with advisory speeds.

In the studies mentioned in Chapter 2, it was found that drivers needed different motivation supports in order to participate in cooperative driving. Some drivers

could clearly explain that their lack of motivation stems from the fear of longer time to destination, and some drivers did not have any explanation apart from “this is not my thing”. It is expected that drivers have different attitudes and beliefs toward cooperative driving. This may be well related to their attitudes and beliefs in driving in general. In other words, drivers’ participation in cooperative driving is influenced by their personal values.

By providing motivation support, CSA helps drivers to establish a new behavior after using CSA for a prolonged period. If CSA accommodates differences in motivation, it may be expected that the newly established behavior will be sustainable. Therefore, it is important that we understand the difference in the ways of supporting motivation as needed by drivers.

This chapter outlines the concept development of the behavior change support system that is to be integrated into CSA. The concept is built around the Persuasive Technology framework, because this framework can be used to address motivation – ability – opportunity. Theoretical frameworks about attitudes, beliefs, behavior change and literature studies about driving behavior are discussed in order to decide the suitable motivation support to be provided by CSA. At the end of this chapter, the functions of CSA and the form of motivation support for drivers are outlined.

6.2. Theoretical Framework

The Motivation-Ability-Opportunity (MAO) (Ölander & Thøgersen, 1995) framework explains that for a behavior to be established, a person needs to have all three determinants to commit the action: motivation, ability, opportunity. The Persuasive Technology framework (Fogg, 2002) provides a suitable implementation of MAO framework within the Human-Computer Interaction domain. This framework can be used to directly assess the interaction between drivers and the CSA system, because the CSA system is also a computer.

According to Fogg (2002), computers may persuade people by acting either as tools, media, or social actors. Computers as tools are making target behavior easier to do, such as leading people through a process, or performing calculations or measurements. These functions support the ability of the person who is interacting with the computer. Computers as media are allowing people to explore cause-and-effect relationships and providing people with a simulation of the environment. These functions deal with feedbacks at the right moments in order to support the exploration and experience, and thus the person interacting with the computer can find opportunities to commit the actions leading to the behavior. Computers as social actors are rewarding people with feedbacks and providing social support. These functions support the motivations of the person interacting with the computer.

In order to learn about the relationship between the MAO framework and Persuasive Technology, existing driving assistance technologies (Fiat, 2010; Ford, 2011; Honda, 2011; MIT, 2009) were explored and identified in terms of their functions as a form of Persuasive Technology. The result of the exploration is illustrated in Appendix D.1. It was found that the existing technologies were mostly classified as Tools, and it was not easy to find examples of Media and Actors types. Also, it was found that a product can provide multiple functions such as Tools+Media or Tools+Actors.

The types of feedback provided by existing persuasive systems were also explored. The feedbacks were categorized into What, When, How, and Who. The How of feedbacks was studied in Chapters 2, 3, 4. The What of feedbacks, supporting the ability of drivers, was partially studied in Chapters 2, 3, 4. The When of feedbacks, supporting the opportunity of drivers, was partially studied in Chapters 2, 3, 4. The Who of feedbacks covers not just Human-Computer Interaction, but also Computer Mediated Interaction or Human-Human Interaction. The result of the exploration is illustrated in Appendix D.2. It was found that apart from the ones studied in previous chapters, feedbacks can also contain time, fuel saving (eco driving), benefits to the whole group vs. individual benefits, and money gained/lost. It was also found that feedbacks can be positive (rewarding) or negative (punishing), and dry (information) or wet (evaluation).

A summary about the MAO framework in marketing science (Hoyer & MacInnis, 2010) states that Ability depends on: Product knowledge and experience; Cognitive style; Complexity of information; Money (to buy the product); Intelligence, education, and age. Opportunity is influenced by: Time; Distraction; Amount, repetition, and control of information. Motivation is influenced by: Personal relevance; Consistency with self-concept; Values; Needs (social, nonsocial, functional, symbolic, hedonic, needs for cognition); Goals; Perceived risk; Inconsistency with attitudes.

Referring to the elements of Ability above, CSA provides ability support consisting of the knowledge about CSA itself and the required behavior change. The complexity of information has been addressed in the studies mentioned in Chapters 2, 3, 4, which addressed the cognitive ability of drivers. Money is not applicable, as CSA may not be a commercial product. Furthermore, we assume that the average drivers have the required intelligence, education, and age to use CSA.

Referring to the influencers of Opportunity above, CSA provides opportunity support by providing information at the right moments. Opportunity support, concerning information delivery at the right moment, raises issues of distraction. The balance between distraction to drivers and the amount and repetition of information has been addressed in the studies mentioned in Chapters 2, 3, 4.

CSA did not yet provide any support for Motivation. Referring to the influencers of Motivation above, the goals of drivers using CSA would be to experience as few traffic jams as possible. The perceived risks in using CSA are safety, time, and social dilemma issues. These issues are perceived differently among drivers, thus they are related to personal relevance, needs, and values in driving. They may be related to the self-concept of each driver, but they are not applicable to be provided by a technology such as CSA. Therefore, we focus on information related to personal relevance, needs, and values among drivers, which is discussed in Section 6.4.2.

In motivation theories, it has been said that people can have either intrinsic or extrinsic motivation to perform a task. Intrinsic motivation concerns the joy or satisfaction in doing a task, while extrinsic motivation is expecting rewards upon the completion of a task. Although sustainable behavior tends to be formed through intrinsic motivation, it can also be formed through extrinsic motivation, as long as the external influencer exists (Thøgersen, 2009).

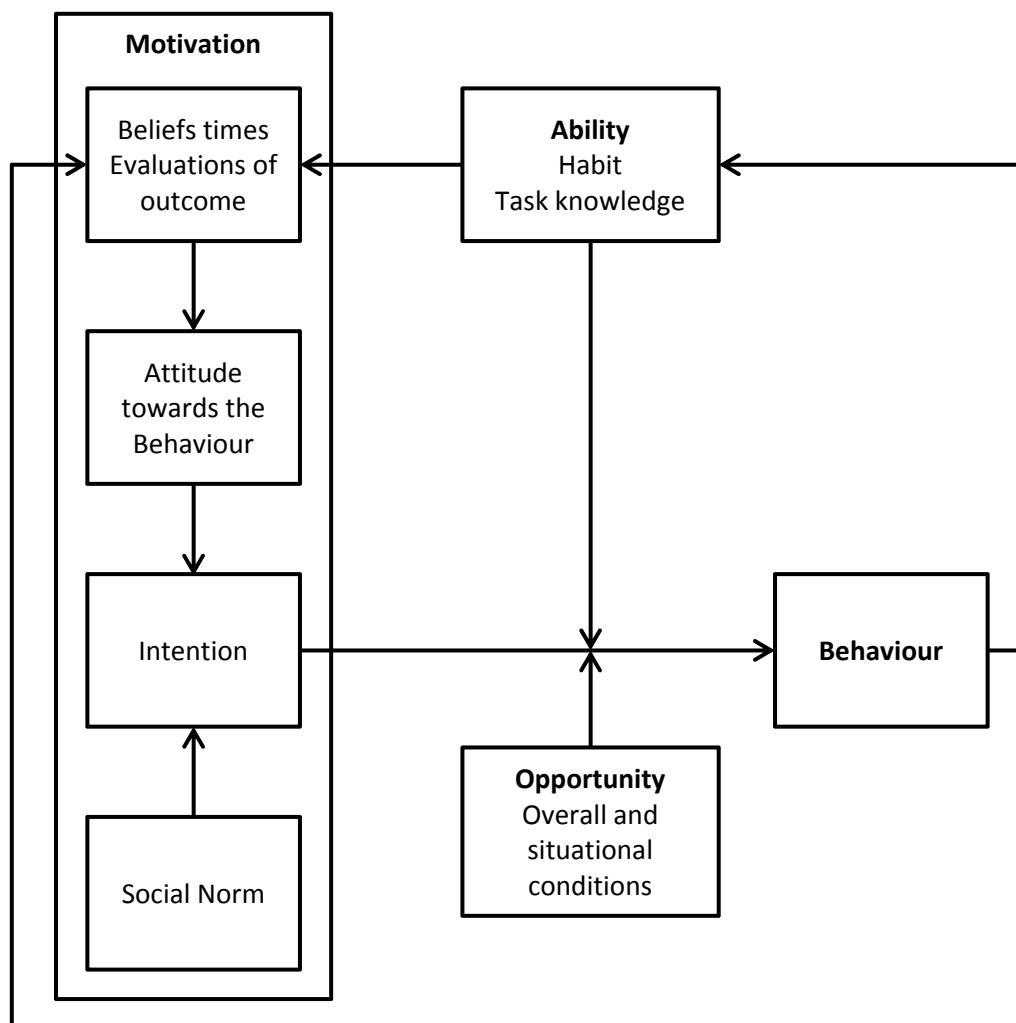


Figure 6.1. The Motivation-Ability-Opportunity-Behavior model (Ölander & Thøgersen, 1995)

For a sustainable behavior, the path to behavior change needs to go through attitude change. For attitude change to happen, people need to acquire a new set of beliefs reinforced by their experiences. According to the MAO framework, beliefs are influenced by existing behavior, ability, habit, and task knowledge (see Figure 6.1). The new set of beliefs is formed when the beliefs are changed after having the experience of doing the task. However, in the beginning beliefs can already be formed by knowing one's ability and having knowledge about the task to be performed. Therefore, it is important to provide meanings to persuade people to start a new behavior.

The Elaboration Likelihood Model (ELM) distinguishes a central and a peripheral route to persuasion (Cacioppo, Petty, Kao, & Rodriguez, 1986). The central route means that people understand the meanings of their action, or people let themselves be persuaded consciously to do the action. It has been linked to intrinsic motivation and associated with high Need for Cognition (NfC) or people's tendency to think and scrutinize about the reasons behind their actions. The peripheral route has been linked to extrinsic motivation (and associated with low NfC). Extrinsic feedback in the form of financial reward may lead to peripheral route of persuasion and the formed behavior is less sustainable (Yamabe, Lehdonvirta, Ito, & Soma, 2010).

Apart from leading to unconscious persuasion, previous studies found that extrinsic financial reward undermines intrinsic motivation (Deci, 1971; Frey & Jegen, 2001; Lepper, Greene, & Nisbett, 1973). However, financial/material reward can be useful for increasing performance of algorithmic behavior (rule-based behavior), but not of heuristic behavior (improvised behavior) (Deci, Koestner, & Ryan, 2001). We decided to use financial reward, because: 1) the accelerate/decelerate actions of driving constitute an algorithmic behavior; 2) looking at the user requirements in Section 6.3.1, people are conscious about money saving as one of the goals of ITS applications, thus financial reward (although extrinsic) is a means of central route persuasion.

By adding financial reward to the existing advisory messages in CSA, we argue that we can persuade both people with high NfC (central route persuasion, intrinsic motivation) and low NfC (peripheral route persuasion, extrinsic motivation). Thus we can minimize the trade-off between providing financial reward and aiming for a sustainable behavior change. If all users of CSA get financial rewards in the beginning of using the system, the ones who do not comply with the advice will change their behavior because of the rewards, and the ones who behave as advised will get their behavior reinforced by the rewards.

6.3. Persuasive Technology Concept

6.3.1. Concept Development

In this thesis, the CSA system is designed for supporting human-computer interactions only. However, a conceptual analysis was conducted on the expected user's experience with the system by taking a more comprehensive perspective. This exploration resulted in the identification of the steps in which users need to be informed about cooperative driving and get their behavior supported. The steps that a CSA system may cover are: 1) raise people's awareness of cooperative driving and influence people to adopt it; 2) help people to find platoons; 3) help people to join platoons; 4) help people to stay in platoons.

In order to raise people's awareness of Cooperative Driving, we might start from social media and social institutions. To influence people's attitude toward CSA, advertising the values and advantages of cooperative driving (such as reducing traffic jams) would be an option, although some people tend to be influenced by their social circle (Cialdini, 2007), and some people tend to be influenced only if they have experienced the system (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009). In order to scope the system to cover only human-computer interactions, this first step is not included in the design of CSA.

The second and the third steps are straightforward to design if we incorporate CSA into existing PND systems (as proposed in Chapter 5). During the trip to a destination, a driver may receive updates about upcoming platoons. While approaching a platoon, the driver is notified of the platoon ahead and assisted to join the platoon. Here, persuasive technology plays a role in persuading drivers to join platoons. This is where CSA provides opportunity support.

The fourth step also may employ persuasive technology in order to keep drivers in platoons. Persuasion can be applied by providing motivational messages that are most suitable to the driver. The motivational messages may range from information concerning the driver's personal values to extrinsic influential factors. This is where CSA provides motivation support.

Further analysis of people's expectations of how CSA would interact with drivers was conducted. Since traffic jams are a strongly acknowledged problem among road users, a number of insights were generated from various road users. They are described in the following paragraph.

Some drivers want to go as fast as they can from point A to B. Dynamic speed limits are not clear, so adding the time it will save to reach the destination is a better solution. Good drivers expect to receive rewards, just like bad drivers receive

punishments. Different types of rewards are expected, both non-material rewards such as compliments and material rewards such as mileage points and tax reduction. Timing of rewards is important, so that non-material rewards such as a smiley sign can be given immediately while driving.

Studies on the nature of driving resulted in an understanding that driving is actually a social activity, due to the necessary cooperation between road users (Swan & Owens, 1988; Vanderbilt, 2008). The studies indicated that the lack of cooperation is one of the causes of traffic jams. How to make drivers cooperate on the road? A motivational source for inducing cooperative behavior is the strong reciprocity of people (Fehr, Fischbacher, & Gächter, 2002). This behavior theory states that people have a tendency to reward cooperators and punish non-cooperators. The existing traffic fine system mainly focuses on punishing non-cooperators. In contrast, rewards ("reverse fine") can be introduced to the ones who cooperate.

Material rewards or incentives are in fact desired by users of ITS, as also reported by two studies on Eco Driving. A study by Man, Bie, & van Arem (2011) reported that in order to promote fuel efficient behavior, the most desired advice is how much money can be saved from the behavior change. This is far more desired (64% among Dutch respondents, 56% among Japanese respondents) than the other types of information (how much fuel is saved, how much CO₂ emission is produced, how much drivers can contribute to environment). A study on rewards for fuel efficient driving among North American drivers (Loumidi, Mittag, Lathrop, & Althoff, 2011) reported that Money is the most desired type of rewards above anything else (Convenience, Fun, Altruism, Competition, Social Recognition). Therefore, these findings support the concept of reverse fine.

Regarding the timing of rewards, immediate feedback has been proven useful for establishing energy saving behavior (Arroyo, Bonanni, & Selker, 2005; Darby, 2001). Immediate negative feedback does not work for a positive long term goal (Ariely, 2009), because people who receive immediate negative feedback cannot delay the gratification (achievement of the positive long term goal) compared to people who receive immediate positive feedback. A negative feedback may result from a negative experience. In order not to delay gratification, an immediate positive feedback should be given right after an intervention that causes negative experience. Translating this theory to the driving context, the positive long term goal in cooperative driving is driving from one point to another without traffic jams. The advice to perform cooperative driving is an intervention that may frustrate personally relevant driving values, which causes a negative experience. In order to give an immediate positive feedback, we consider immediate non-material reward while driving. In addition, the immediate feedbacks allow drivers to monitor their behavior from time to time, which serves as an opportunity support.

Questions from various road users acknowledged issues explained by the theory of social dilemmas (Hardin, 1968). Such a question is: “How do we persuade drivers to start following CSA advice without letting them worry whether other people will follow CSA or not?” This was confirmed by an observation that people seem to be “fooled by traffic jams” in terms of perception of time and social justice (Vanderbilt, 2008). This perception leads to driver’s behavior of constantly/needlessly changing lane because the other lane seems faster. This issue was also identified in the focus group discussions described in Chapter 2. Therefore, CSA should help people in overcoming the illusion of faster lanes and gaining time.

6.3.2. Concept Test

The concept for CSA is scoped to support only the third and fourth steps as mentioned in the previous section: assisting drivers for joining and staying in platoons. In order to test the features discussed in the concept development, several concepts were sketched. For the concept test, several designers were invited to evaluate the sketches heuristically. This test aimed to evaluate the Ability Support, Opportunity Support, and Motivation Support as the possible functions of CSA. The test also aimed to evaluate the concept of immediate feedback and material rewards.

The first concept is aimed at Ability Support, where CSA supports the ability of realizing the proper speed by informing the driver about current and target speed/acceleration. As shown in Figure 6.2, the left frame has a green border indicating “speed up” advice, the middle frame has a normal navigation information display, the right frame has a red border indicating “slow down” advice. The navigation information dims in order to display the details of the advice over it. The pie-shape visualization on the left frame and the right frame indicates the extent (more pie slices = larger extent) of the acceleration and deceleration respectively, to be applied by drivers. The numbers 120 and 90 indicate the target speeds that drivers need to comply with. This concept was evaluated as useful and reasonable.



Figure 6.2. Concept of Ability Support: Too Slow, Appropriate⁶, Too Fast conditions

The second concept is aimed at Opportunity Support, where CSA supports the opportunity for realizing the proper speed by informing the driver about when to change his/her speed in order not to cause a traffic jam. The traffic jam’s

⁶ Navigation display taken from TomTom (2009)

growth/shrinkage is linked with the information about its length (in time) and simulated graphically, as shown in Figure 6.3. This concept was evaluated as providing better opportunity support compared to the existing traffic information system such as the traffic jam information from the radio.

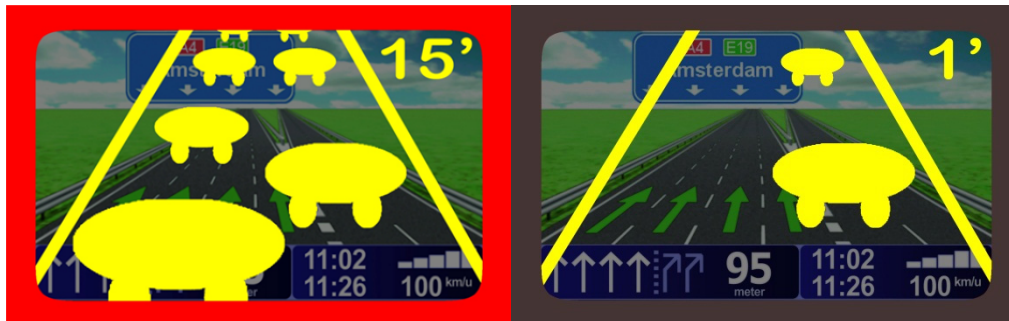


Figure 6.3. Concept of Opportunity Support: traffic jam length in time. When the driver receives an advice for slowing down, a simulated traffic jam is displayed (15 minutes), including the time delay that the traffic jam will cause. The driver can slow down until the red color disappears, indicating very little time delay (1 minute).

The third concept is aimed at Motivation Support, where CSA shows the “happiness” of the system with a smiley. The smiley turns to sad when the driver is too slow/fast and turns to happy again when the driver reacts properly to the system. The curve of the smile is variable, i.e. the more the driver reacts properly, the happier the actor is. This concept was evaluated as having low motivational force.

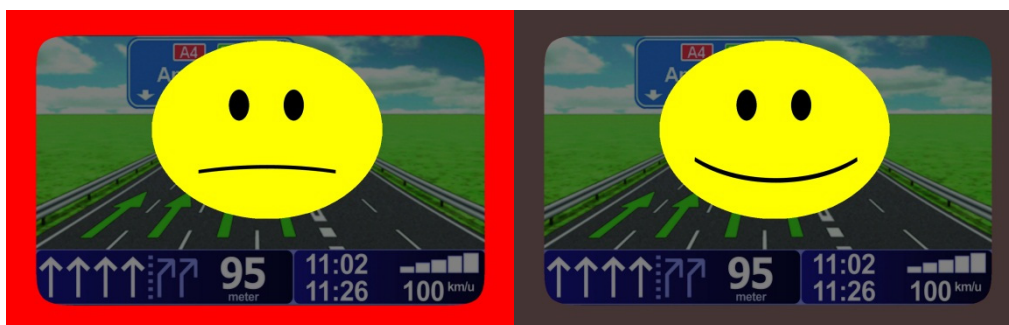


Figure 6.4. Concept of Motivation Support: sad and happy system condition.

The fourth concept concerns Material Rewards, where the driver can: 1) Earn credits depending on the frequency of compliance (as shown in Figure 6.5); 2) Achieve a score reflecting the driver’s positive influence on the traffic jam (as shown in Figure 6.6). Both the credits and score are exchangeable with material rewards outside the traffic system. This concept was evaluated as promising, because material rewards can be suited to different types of driver’s personal needs, such as getting free mp3, fuel discount, and tickets to entertainment shows.



Figure 6.5. Concept of Material Rewards integrated with the concept of Opportunity Support. The driver receives an advice with simulated traffic jam and time delay information, but as a car disappears from the traffic jam (graphic: a car fading out) a 10-point credit is obtained. For each disappearing car, the driver receives a 10-point credit.

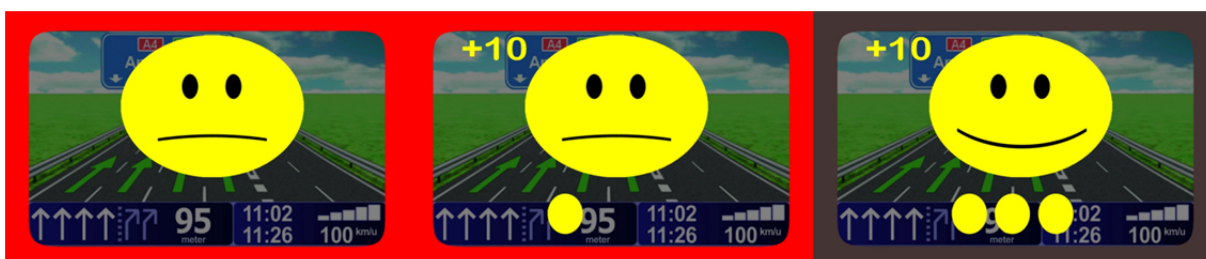


Figure 6.6. Concept of Extrinsic Feedback: extension of the concept of Motivation Support. The driver receives an advice with a sad smiley. Each time the driver reacts, the smiley reacts by displaying an egg at the bottom indicating 10-point score that is obtained by the driver. After three eggs, the smiley is back to happy.

Overall, the concepts received positive judgments. However, before they can be implemented in the design, each of the Motivation, Ability, Opportunity supports needs to be refined. As discussed in Section 6.2, driver's abilities that will be supported are adjusting speeds and monitoring speed compliance by getting immediate feedbacks on the result of the driver's actions. Driver's opportunity that will be supported are getting information at the right moments in order to overcome the illusion of faster lanes and gaining time. Driver's motivations that will be supported are related to the driver's values, personal relevance, and needs. This is discussed in the next section.

6.4. Differences in Motivation

This section discusses the persuasion literature that is relevant for identifying differences in motivation among drivers. In order to address different motivation supports, literature on driving values that are related to drivers' attitude and behavior is also discussed.

6.4.1. Persuasion Profiles

People differ in terms of their susceptibility to persuasion (Cialdini, 2007). Some people may be influenced by their social circles, and some people may be influenced by their intrinsic motivation, be it only knowledge or experience. Moreover, the extent to which a person processes a message through the central route of persuasion is largely influenced by personal involvement with a message (Cacioppo et al., 1986).

Looking at personal relevance as an influencing factor of motivation (Section 6.2), personally relevant messages become essential in a persuasive system. Persuasive Technology allows for personalized persuasion (Fogg, 2002); this advantage urges the use of personalized persuasion in a persuasive system like CSA.

There are numerous categorizations of persuasion strategies (Rhoads, 2007). For example, Kaptein, Duplinsky, & Markopoulos (2011) proposed Persuasion Profiles by characterizing a user as to the type of persuasion he/she is most susceptible to in system usage based on the categorization by Cialdini (2007), for example authority and social proof. Using the authority strategy, the system persuades users by using arguments coming from an authority figure. Using the scarcity strategy, the system persuades users by using arguments coming from their social groups.

We argue that categorization of persuasion strategies can be generated based on the context of the development of a persuasive system. As analyzed in Section 6.2, persuasion strategies can be categorized through: central vs. peripheral route; and intrinsic vs. extrinsic motivation. The variety of people's values, personal relevance, and needs can be utilized as targets for persuasion strategies.

6.4.2. Driving Values as Persuasion Strategies

The personal driving values to be used in this research are the ones influencing or influenced by adjusting speeds in traffic, such as speed choice, accelerating and decelerating, and timing. A study on speed choice (Stradling, 2007) indicates that speed choice is influenced by three factors. The first factor is the driver's and the car's ability to reach a certain speed and the road conditions. The second factor is the obligation by time or route, for example someone who drives as part of his/her job. The third factor is driver's inclination to make a speed choice. This study also reports the result of a questionnaire study eliciting reasons on driving slower and driving faster. Three reasons were factorized: safety, responsibility to others, and arousal or emotional state.

Social issues can also influence speed choice, i.e. drivers tend to speed more when driving alone than when driving with passengers (Fleiter, Lennon, & Watson, 2010). Fleiter et al argued that what matters is not social pressure, but being responsible for the safety and the comfort of the passengers. People want to be known as responsible, considerate, and/or trustworthy.

Studies on the relationship between driver's intentions and speed choices provide additional information on what are the personally relevant values to each driver. These studies used the Theory of Planned Behavior (TPB) (Ajzen, 1991). This framework enhances the MAO framework, because it addresses how intention influences actions. Intentions are influenced by behavioral beliefs, control beliefs, and

normative beliefs. Behavioral beliefs are what people think about the consequences of their behavior. Control beliefs are an individual “beliefs about the presence of factors that may facilitate or impede performance of the behavior” (Ajzen, 2006). Normative beliefs are the social norms as in the MAO framework (as in Figure 6.1). The personally relevant values are the behavioral beliefs and the control beliefs.

Elliott, Armitage, & Baughan (2005) established a link between behavioral beliefs and the likelihood of complying with the speed limits, and a link between control beliefs and the likelihood of exceeding speed limits. The behavioral beliefs (expected outcomes) underlying compliance with the speed limits are to feel relaxed, to use less fuel, to reduce chances of an accident. The control beliefs underlying exceeding the speed limits are about the presence of factors such as when being late and driving on long straight roads. Wallén Warner & Åberg (2008) reported similar findings on behavioral beliefs and control beliefs. They concluded that drivers see safety measures such as good roads to make it easier to exceed speed limits, and drivers who intend to exceed speed limits notice the speed signs and more easily disregard them. Driving on a well-known road and driving on a smooth road as the cause of a speed increase are also reported by Leandro (2012) as control beliefs.

De Pelsmacker & Janssens (2007) reported that habit formation and the attitude toward speeding influence the intention toward speeding. Paris & Broucke (2008) reported that intention and perceived control cannot predict actual speeding behavior. This attitude-behavior inconsistency is also as reported by Goldenbeld, Levelt, & Heidstra (2000), who outlined behavior as three types: planned/reasoned, impulsive/emotional, and habitual. They also inferred the factors that influence speeding: Pleasure, Risk, Time, Costs. Moreover, they mentioned skills and situational factors as the explanation to the attitude-behavior inconsistency. This confirms the usefulness of the MAO framework, as it addresses skills (ability) and situational factors (opportunity).

Summarizing the studies discussed above, this section generates insight for providing different motivation supports. The motivation supports that are relevant to personally relevant values may cover a wide range of values: safety, being responsible to others, emotional state like having fun, feeling relaxed, eco driving issues, time saving, and money issues.

6.5. Conclusion

In this chapter we have analyzed the factors required to support behavior change in cooperative driving through the MAO framework. The choice of the MAO framework over other attitude-behavior frameworks – such as TPB – is suitable for CSA application, because it takes into account habitual factors that are important for non-conscious decisions and routines as the studies above suggested. This is relevant

for the behavior of complying with the advice of CSA, because it can be a routine behavior and will eventually result from non-conscious decisions after the behavior change is established.

This work is comparable to other studies that also employed the MAO framework. One study (Graml, Looock, Baeriswyl, & Staake, 2011) also proposed the use of immediate feedback, positive feedback, and tailored communication (in other words: persuasion profile). Another study (Thøgersen, 2009) successfully used material rewards to temporarily change behavior that induced new beliefs.

The Ability and Opportunity supports of CSA are comparable to previous studies about speed limit information on the road side that gives feedback on a driver's speed (whether the current speed is too fast or appropriate) at certain residential zones. Spiegel, Kalla, Spiegel, Brandt, & Strupp (2010) reported that placing speed limit displays on two locations led to a significant number of drivers complying with the speed limits, because they had the opportunity to assess the reduction of their speeds between the first and the second displays. Jeihani, Ardeshiri, & Naeeni (2012) reported that such a system is only useful for a short period of time, because drivers increased their speed again after passing the speed limit displays. CSA gives both immediate feedback at the right time and continuous feedback for as long as the speed limit applies.

Summarizing the concept test and the literature studies, the functions of CSA to be tested in a driving simulator experiment are to help drivers to join and stay in platoons. Persuasive Technology is employed in order to provide the following supports:

- Ability support: advising drivers on adjusting their speeds, giving immediate feedbacks on the result of driver's actions
- Opportunity support: presenting the information at the right moments, overcoming the illusion of faster lanes and gaining time
- Motivation support: persuading drivers with messages addressing personally relevant driving values and material rewards

7

The Development of Personal Driving Values Questionnaire

This chapter continues from the previous chapter about supporting driver's behavior change through personal driving values. This chapter discusses how driver's motivation to adjust speed can be influenced by personal driving values. In this chapter, we describe the development of the Personal Driving Values (PDV) questionnaire. The questionnaire is to be used as a means of identifying personal values of drivers, in order to identify persuasion profiles. The development of the questionnaire items was inspired by other driving questionnaires, but the aim is to extract several factors that represent the personally relevant values in driving. The 49-item questionnaire was distributed to 250 drivers, and the exploratory factor analysis resulted in a final 22-item questionnaire addressing non-monetary driving values.⁷

⁷ This chapter is based on:

Shahab, Q., Terken, J., Eggen, B. (2013). *Development of a Questionnaire for Identifying Driver's Personal Values in Driving*. Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp.202-208). Eindhoven, Netherlands, ACM Press.

7.1. Introduction

In order to find out the relevant values for cooperative driving and categorize drivers with respect to their personal driving values, a questionnaire was prepared. This questionnaire is called the Personal Driving Values (PDV) questionnaire or PDV-Q. As discussed in Section 6.2, the values differ across individuals, and can support motivation. As discussed in Section 6.4.1, the values can be used for different persuasion strategies, from both extrinsic-intrinsic sources of motivation and through both central-peripheral routes to persuasion.

There are a number of studies concerning the construction and validation of questionnaires about driver behavior. Reason, Manstead, Stradling, Baxter, & Campbell (1990) introduced the Driver Behavior Questionnaire (DBQ). DBQ has four factors: errors, lapses, ordinary violations, and aggressive violations. DBQ was validated several times (Ozkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006), showing that the four factors can be refactorized into two factors: driving skills and driving styles. West, Elander, & French (1992) developed the Driving Style Questionnaire (DSQ), which was used to classify driving test participants (Hoedemaeker & Brookhuis, 1998). Although driving styles may relate to personal driving values, the DBQ and DSQ are for self-reporting the mere existence of the behavior, not as a means of relating them to personal values.

Some of the studies using the Theory of Planned Behavior (TPB) mentioned in Section 6.4.2 also used questionnaires in order to factorize the statements into factors of TPB (beliefs, norms, perceived control, intention). While we can use the behavioral beliefs and perceived control beliefs from those questionnaires, they are also not sufficient due to lack of habitual factors. De Pelsmacker & Janssens (2007) addressed habit formation, but it was only about speeding.

The PDV-Q is designed to be a self-reporting means of behavior in various conditions and the personal values underlying that behavior. The behavior is measured by frequency of occurrence (Never to Always). The conditions may consist of beliefs, attitudes, and situational/habitual context, but we are not going to separate the different types of condition, thus the name: personally relevant driving values.

This chapter describes the construction of PDV-Q based on related studies and brainstorming with drivers, and the scale construction of PDV-Q after distributing the initial questionnaire to 250 drivers. The factorized questionnaire is analyzed and driving values are extracted. The use of the extracted driving values to determine persuasion profiles is discussed at the end of the chapter.

7.2. Items Construction

The items used in the studies mentioned in Section 6.4.2 were used as a starting point in generating questionnaire items about personal values as determinants of driving behavior and financial issues in traffic. A brainstorm with two designers was conducted in order to come up with personally relevant values in relation to their behaviors while driving. The brainstorm participants drove approximately 1-2 hours per week (every weekend), they did not commute with cars i.e. they used cars only for non-obliged trips. They understood that driving faster does not always save time. This brainstorm generated several driving values. In another brainstorm, we complemented and finalized the driving values into 7 categories: Safety, Time, Comfort/Ease, Fun, Money, Being a good driver, Sustainability (nature issues).

From both brainstorms, 52 items belonging to the 7 categories were generated. They were randomized and presented in a questionnaire. The items in the questionnaire are statements, each describing a behavior and the underlying motivation for exhibiting that behavior, as in Table 7.2. Respondents can then indicate on a 7-point scale how often (from 'Never' to 'Always') they display the specific behavior for the stated reason. After inviting two pilot respondents to fill in and evaluate the questionnaire, 49 statements were finalized.

Table 7.1. *Driving values, motivation, and persuasion route*

Values	Intrinsic	Extrinsic	Central	Peripheral
Comfort/Ease	x		x	x
Fun	x		x	x
Safety	x	x	x	
Being a good driver	x	x	x	
Sustainability	x	x	x	
Time	x	x	x	x
Money		x	x	x

The 49 statements cover both intrinsic and extrinsic motivations, routed through both central and peripheral persuasion, as shown by Table 7.1. Fun and Comfort/Ease are exclusively intrinsic, because it is a subjective aspect of driving. Money is exclusively extrinsic, because it is about material rewards/penalties. The other values (Safety, Being a good driver, Sustainability, Time) can be both intrinsic and extrinsic. Regarding the route of persuasion, Safety, Being a good driver, and Sustainability are exclusively central. This is because a driver needs a strong reason (influenced by attitude) to change their speeds when it comes to safety, driving well, and taking care of the environment. The other values (feeling comfortable, having fun, winning time, getting money) can be both central and peripheral. This is because in order to feel comfortable, have fun, win time, get money, there are both relevant and irrelevant reasons. The examples of irrelevant reasons: Avoiding speed ticket leads to feeling comfortable, thus it influences speed choice (Mannering, 2009; Tarko, 2009);

Increasing speed for the sake of having fun (Peer & Rosenbloom, 2012); Increasing speed because of time-saving bias (Peer, 2011).

Table 7.2. The questionnaire items and their driving value categories

Code	Statement	Never	Always
Comfort1	I drive slower at night, because a slower speed makes me feel more comfortable under reduced vision circumstances.	1	1
Comfort2	I drive faster only when the road allows me to drive faster (wide, straight).		1
Comfort3	I drive more aggressively when I'm late because I get nervous of my own lateness.		
Comfort4	I drive slower because it's more relaxing.		1
Comfort5	I maintain a large distance to the car in front of me while driving, because it's more comfortable.		1
Comfort6	I stay on the safe side of the speed limit, because I feel more relaxed.		1
Comfort7	I like driving behind another car, even if it's slow, because I find it relaxing.		1
Fun1	I overtake cars driving slower than I like to drive, because it's boring to drive that slowly.		1
Fun2	I drive faster when there is less traffic, because driving fast is fun.		1
Fun3	I drive faster because I love the adrenalin rush.		1
Fun4	I drive really fast, because it is boring to drive in the highway.		1
Fun5	I overtake other cars, because it keeps me engaged.		1
Fun6	I like driving because it feels like a sport/game.		1
Good1	In dense traffic, I maintain a shorter distance to the car in front of me, because I don't want to obstruct the traffic.	1	1
Good2	I drive slower when I have passengers, because I care about their peace of mind.		1
Good3	I drive faster when I have passengers, because I want to appear brave.		
Good4	I try to drive well to set a good example to other road users.		1
Good5	If the traffic light becomes green I try to leave quickly, because I don't want to obstruct the traffic.		1
Good6	When overtaking, I speed up and try to be in the inner lane as short as possible, because I don't want to obstruct upcoming traffic.		1
Good7	I adjust my speed according to the matrix boards, because it enables a smooth traffic flow.		1
Good8	I get annoyed by people who don't use their indicators before turning.		1
Good9	I get annoyed by people who obstruct traffic flow.		1
Good10	I'm very conscious of speed cameras, because I want to keep a clean record.		1
Money1	I try to drive as energy efficient as possible because it saves fuel costs.	1	1
Money2	I'm very conscious of speed cameras, because I don't want to pay for speed tickets.		1
Money3	I drive slower because it saves fuel costs.		1
Money4	I reduce my speed when other cars suddenly slow down, because it may indicate that there is a speed camera.		1
Money5	I drive to a petrol station further away to save money on the fuel price.		1
Money6	I drive to a parking lot further away to save money on the parking rate.		1
Money7	I make pleasure trips regardless of the costs of driving.		
Safety1	I drive slower when I have passengers, because I care about their safety.	1	1
Safety2	I let myself be distracted by passengers, so that I don't pay attention to the speed and may drive faster or slower than I normally drive.		
Safety3	I adjust my speed in dense traffic, because I don't want to cause accidents.		1
Safety4	I drive slower when the speed limit goes down, because speed limits are intended to improve safety.		1
Safety5	When the traffic is slow, I drive slower than I normally drive.		1
Safety6	When the traffic is faster, I drive faster than I normally drive.		1

Sustain1	I drive as I like, because the environment sustainability is the government's responsibility.	1	
Sustain2	I drive slower because it produces less CO2 emission.		1
Sustain3	I try to drive as energy efficient as possible, because it's better for the environment.		1
Sustain4	When I drive I think about my car's CO2 emission, because I don't want to pollute the air.		1
Sustain5	I try to use the car only when it's needed, in order to save the environment.		1
Sustain6	I try to apply "eco driving" techniques (het "nieuwe rijden"), because it saves the environment.		1
Time1	I drive faster when I am late for an appointment.		1
Time2	I want to drive as fast as possible to my destination.		1
Time3	I overtake cars driving slower than I like to drive, because they slow me down.		1
Time4	In traffic jams I often shift lanes in order not to lose time.		1
Time5	I want to be able to predict the time to my destination.		1
Time6	I find traffic jams annoying, because I tend to depart on the last minute.		1
Time7	I find traffic jams annoying, because I hate getting late.		1

Each driving value is represented by 7 to 10 statements, in order to leave a sufficient number of statements if the validation reduces the number of statements that apply to each driving value. A rule of thumb is that in the final questionnaire each value should be represented by at least four items. The final driving values are used to describe the persuasion profiles, where each value represents a persuasion strategy.

In Table 7.2, the 49 statements of the questionnaire are listed. The occurrence of each statement (behavior with its specific reason) is to be rated from Never to Always, with a 7-point Likert scale. Most of the statements are positively phrased (number '1' under 'Always' column), meaning that an Always (7) answer to these statements contributes positively to the score of the driving value. Some statements are negatively phrased, meaning that an Always (7) answer to these statements contributes negatively to the score of the driving value. For example, statement Comfort3 has "1" under "Never" column, thus answering Never (1) to this statement represents greater Comfort value in driving.

7.3. Data Collection

At least 200 respondents are needed for validation of the questionnaire. The required number of respondents was calculated based on our aim of having at least 4 factors, multiplied by the number of items ($4 \times 49 = 196$, so 200 to be safe). Respondents were required to be driving on a regular basis, at least two times per month. In order to ensure this requirement, preamble questions were presented before the actual questionnaire, as in Figure 7.1 below. Respondents were required to report their driving frequency through a multiple choice question, and people who drove less frequently than 2 times per month were expected to discontinue filling in this questionnaire. In addition, respondents were required to report their main purpose of driving, because people who drive for work purpose may have obligations that influence their driving behavior, as observed by Stradling (2007).

*** Required**
I drive... *

☐ Every day
☐ Several days per week
☐ Every week
☐ 2 to 4 times per month

I drive mostly for... *
 "Leisure" e.g. going out on a sunday, going to a restaurant / theater; "Other" e.g. taking children to school, regular grocery shopping, visiting someone in the hospital

☐ Work
☐ Leisure
☐ Other:

Continue »

Figure 7.1. The catch questions at the beginning of the questionnaire

The questionnaire was offered in two versions: Dutch and English. The questions of the Dutch version were translated as much as possible such that the meaning was preserved, rather than aiming for a literal translation. The Dutch questionnaire was distributed via Twitter and Facebook through our network in the Automotive domain and the Industrial Design domain, as well as personal contacts. It was also distributed on Dutch and Flemish online forums about automotive. The English questionnaire was distributed through contacts in Australia and USA.

Respondents were provided with the following instruction: *How do I drive in the highway? This survey is about how you drive. It consists of 49 statements. It will take you approximately ten minutes. Important: Most of the statements have the form "I do this because [reason]". For each statement, please answer how often the statement applies for the stated reason. Your answer may range from 1 [Never] to 7 [Always]. For example: "I overtake other cars, because it keeps me engaged". You should chose "7" if you do it always for the stated reason. If you overtake other cars a lot, but for other reasons, then you should choose "1".* This instruction was intended to avoid misunderstandings of self-reporting the behavior without taking the reason into consideration. After filling in the questionnaire, each respondent had to fill in their demographic data (age, gender, country of residence).

In total, 250 people (61 female, 189 male, age 17 to 78, mean age = 34.27) filled in the questionnaire. According to countries of residence, 105 Flemish, 96 Dutch, 13 Australian, 11 British, 11 American, 5 German, 3 Indonesian, 1 Danish, 1 French, 1 Luxembourger, 1 Norwegian, 1 Romanian, 1 Singaporean respondents filled in the questionnaire. 205 of them were regular drivers (several days to every day per week), and 45 were occasional drivers (2 to 4 times per month or once per week). 161 of them drove primarily to work including the ones driving to school, and 57 of them

drove primarily for leisure. Only 3 of them indicated driving for both, and 5 of them indicated driving for everything. The rest (24 people) drove for different purposes such as shopping, taking care of family members, for specific obligations, and when they were not able to commute using public transport.

7.4. Scale Construction

The questionnaire responses were processed with exploratory factor analysis. Before performing the analysis, we need to consider whether the sampling adequacy is good, which means that there are enough responses. Therefore, Kaiser-Meyer-Olkin (KMO) test of sampling adequacy and Bartlett's test of sphericity were done. The score of the KMO test was more than .8, which is a very good score for sampling adequacy. Bartlett's test showed significant difference ($p < .001$) from identity matrix, which is good (Field, 2009) and indicates that the set of items is factorable.

Using exploratory factor analysis, initially 14 factors were extracted from the 49 items. Several very strong factors were found: Speed Cameras {Money2, Money4, Good10}, Annoyance {Good8, Good9}, Passengers {Safety1, Good2}, Money {Money5, Money6}. The labeling of these factors was taken from the same words used in those items: Money2, Money4, Good10 address speed cameras; Good8, Good9 deal with being annoyed; Safety1, Good2 concern passengers; Money5, Money6 contain "money". They did not load together with any other items, i.e. they formed separate factors consisting of items that were very strongly correlated with each other. These items were removed, because our constraint is to have at least 4 or 5 items per factor. The items of Annoyance were presented next to each other in the questionnaire items presentation (and similarly with the items of Passenger), so it may have caused the strong correlation.

The exploratory factor analysis was repeated while removing the statements having less than .4 value in the Rotated Component Matrix table. The statements loading on more than one factor were also removed. In the end we had five factors, as in Table 7.3.

Because the five factors were newly created, the inter-item reliability for each factor was analyzed. The purpose of the inter-reliability analysis is to make sure that the items constituting a factor are highly correlated with each other. The scale inter-reliability of each factor was assessed using Cronbach's Alpha analysis, where an Alpha value of at least .7 is considered a good correlation value. The outcomes of the Cronbach's Alpha analysis were as follows:

SUSTAIN:	Sustain3, Sustain4, Sustain6, Sustain2, Sustain5, Money1	Alpha = .902
FUN:	Fun2, Fun3, Fun6, Fun4, Fun5	Alpha = .845
RELAX:	Comfort7, Comfort4, Comfort6	Alpha = .706
SAFETY:	Safety3, Comfort5, Good7	Alpha = .597
TIME:	Comfort3, Time6, Time7, Time3, Time4	Alpha = .596

The RELAX, SAFETY, TIME factors were updated, in order to incorporate more statements from the original factors into the final questionnaire. Using Cronbach's Alpha, the added items were assessed for reliability. Time1 increased the Alpha value of TIME, Safety4 increased the Alpha value of SAFETY, and Time2 increased the Alpha value of RELAX. When factor analysis was performed again, Time2 also loaded under TIME. Since RELAX had already .7 Alpha, Time2 was removed again from RELAX. The introduction of Time1 caused the factor analysis create an extra factor containing Time3 and Time4. Time4 was removed, because it reduced the Alpha more than Time3 did. All items in FUN were highly correlated, but Fun6 was removed and Fun1 added again, because Fun6 more likely describes attitude instead of behavior. Money1 was removed from SUSTAINABILITY, because it mentioned fuel cost instead of just pure sustainability.

The Speed Camera items were added again, because they were not located next to each other in the questionnaire presentation. The Annoyance, Passengers, and Money related issues stayed excluded, because they were presented next to each other in the questionnaire (in order to remove biased answers). There were six factors, as described below:

SUSTAIN:	Sustain3, Sustain4, Sustain6, Sustain2, Sustain5	Alpha = .903
FUN:	Fun2, Fun3, Fun1, Fun4, Fun5	Alpha = .860
RELAX:	Comfort7, Comfort4, Comfort6	Alpha = .706
SAFETY:	Safety3, Comfort5, Good7, Safety4	Alpha = .597
TIME:	Comfort3, Time6, Time7, Time3, Time4	Alpha = .596
SPEEDCAM:	Money2, Money4, Good10	Alpha = .642

For social psychology data like human behavior, oblique rotation is more appropriate to be used in the exploratory factor analysis, because it allows correlation between factors. A new factor analysis was conducted again, with only

It is evident from Table 7.4 and Table 7.5 that each factor in the questionnaires consists of the same sequence of items. Both the 22-item (five factors) and the 25-item (six factors) questionnaires load the five factors with good correlations. Therefore, the final questionnaire is the 25-item one. The results from the 25-item questionnaire are discussed in the following section in order to identify possible driver profiles.

7.5. Driver Profiles

In order to get an overview of the distribution of the personal driving values, the average scores for each factor were calculated, and classified as low (less than or equal 3 on a 7-point scale), mid (larger than 3 and smaller than 5) and high (more than or equal 5 on a 7-point scale). These scores are calculated by taking the average of the scores of the individual items. The SPEEDCAM factor was relabeled as FINES (traffic fines). The distribution of the low, mid, and high scores is shown in Figure 7.3. The figure shows that at least half of respondents scored high in Time, Safety, and Fines, and that more than half of respondents scored low in Sustainability. This overview suggests that it may not be easy to find a driver with high Sustainability score, while it may be easy to find a driver with high Fines, Safety, or Time score. These high scores suggest that people are more likely to maintain the speed limit for avoiding fines, for safety reasons, and to violate the speed limits in order to reduce the time to destination.

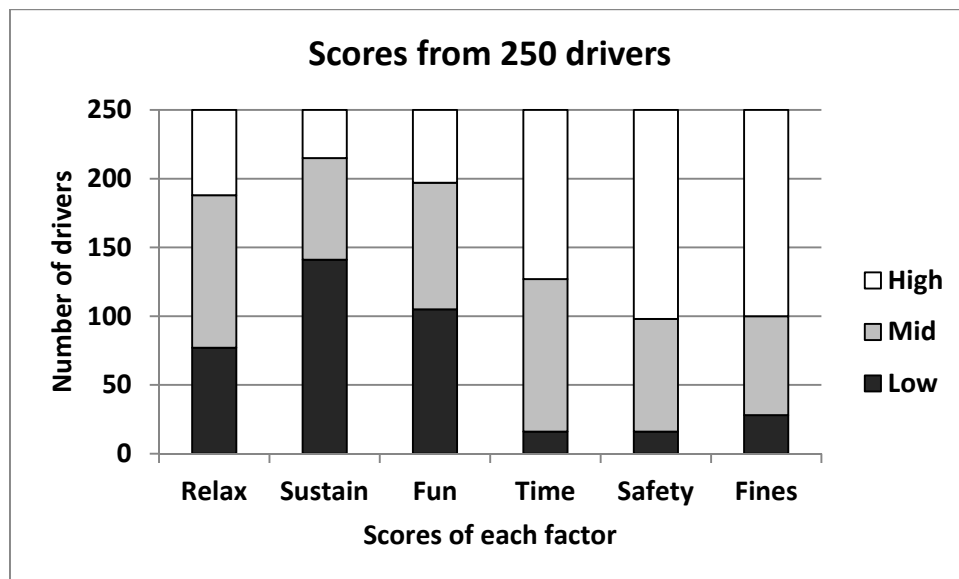


Figure 7.2. Distribution of low, mid, and high average scores for each factor

A correlation analysis was performed in order to find how scores of each factor correlated with each other. Relax and Safety are moderately correlated ($r=.451$, $p<.001$) so are Relax and Sustain ($r=.455$, $p<.001$). Relax and Fun are negatively correlated ($r=-.484$, $p<.001$), and Fun and Time are slightly correlated ($r=.369$, $p<.001$). Therefore, scores for Relax-Safety-Sustain were summed and compared with the sum of the scores for Fun and Time. It was found that Relax-Safety-Sustain and Fun-Time are

negatively correlated ($r=-.582$, $p<.001$). Thus, a driver who has a high score for the Relax-Safety-Sustainability cluster is likely to have a low score for the Fun-Time cluster. In addition, a driver may have high scores for two or three factors, if the factors are in the same group (Relax-Safety-Sustain or Fun-Time).

Table 7.6. Correlations between scores for different factors

	Relax	Sustain	Fun	Time	Safety	Fines
Relax		0.46	-0.47	-0.19	0.46	0.00
Sustain			-0.44	-0.26	0.38	-0.26
Fun				0.37	-0.43	0.30
Time					-0.02	0.32
Safety						0.07
Fines						

The next step was to determine the driver profiles on the basis of the scores of the individual respondents on the different factors. There are several ways to define the notion of driver profile. One way to do this might be in terms of radar plots, simply representing the scores for the different factors for an individual respondent, as in Figure 7.3. This definition of profile is similar to the one proposed by Kaptein & Halteren (2012). However, this definition makes it hard to draw general conclusions about the dominance of particular factors across respondents.

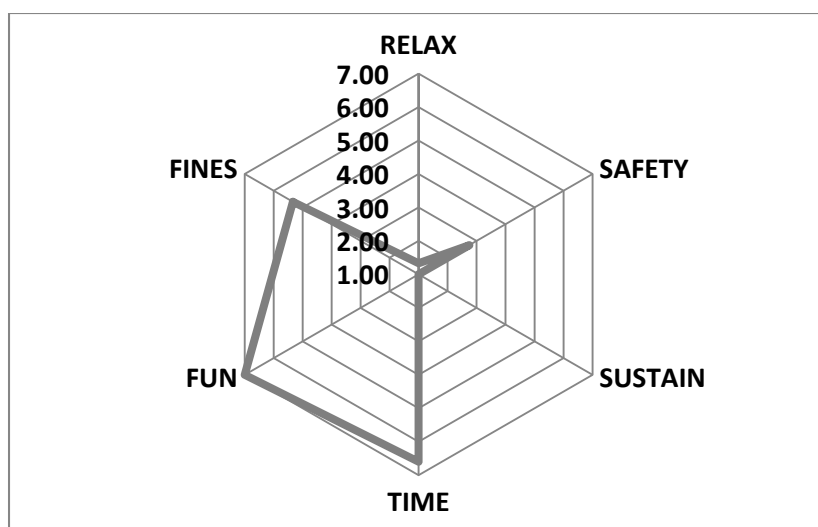


Figure 7.3. Radar plot showing the profile of a respondent

We therefore defined the persuasion profile of a driver as the persuasion strategy that the driver is most susceptible to. In this case, the driver is expected to be sensitive to persuasive messages addressing the factor relevant to his/her strongest personal value in driving. This is characterized by the strongest factor based on the driver's questionnaire response.

A relevant study (Kaptein, de Ruyter, Markopoulos, & Aarts, 2012) used a questionnaire to determine persuasion profiles of participants of a persuasion experiment. The study determined a participant's strongest sensitivity to persuasion strategy by obtaining the factor with the highest score based on his/her questionnaire response. However, the study did not take into account that a participant's strongest sensitivity to a persuasion strategy may be less strong than another participant's weakest sensitivity to the same persuasion strategy. Applying this in the current context, it would mean that, if participant A scores 1 in Safety and 3 in Fun, and participant B scores 4 in Fun and 5 in Time, then participant A is classified as having a Fun profile and participant B as having a Time profile, although participant B scores higher in Fun compared to participant A. Therefore, we applied a slightly modified version of Kaptein et al.'s definition.

In our case, the profile was determined as follows. First we calculate the average score for a driver and the standard deviation (SD); then we take the factor that scores the highest, provided it exceeds the (average+SD) threshold. For example, a driver scores a for Sustain, b for Fun, c for Relax, d for Time, and e for Safety, then his/her standardized score is obtained from the average(a,b,c,d,e) + SD(a,b,c,d,e). Now, if a is higher than the average+SD value, then the driver has a Sustainability profile. Similarly for determining a driver's persuasion profile out of six possible factors, the profile can be determined from computing average(a,b,c,d,e,f) + SD(a,b,c,d,e,f) where f is the score for Fines. If no score is higher than average+SD value, then the driver is considered not to have a dominant personal value, i.e. his/her persuasion profile cannot be determined. This method still has limitations. If a driver for instance has 5-6-5-6-5 (average=6) score, he/she is sensitive to several persuasion strategies (all factors score high), but we cannot label his/her profile with a particular persuasion strategy. Therefore, this driver's persuasion profile cannot be determined.

Applying this method, the charts in Figure 7.4 list the number of driver profiles obtained from the 250 respondents. The six profiles were obtained from scores of the 25-item questionnaire, and the five profiles were obtained from scores of the 22-item questionnaire. The 6-factor chart shows fewer respondents (57) whose persuasion profile could not be determined, compared to the 5-factor chart (68 respondents). This reduction is probably due some of them exhibiting a Fines profile. Similarly, the 6-factor chart shows fewer respondents with a Safety profile compared to the 5-factor chart, also maybe due to the Fines profile. This overview suggests that influencing drivers with Safety and Time messages would be what CSA would do for most drivers.

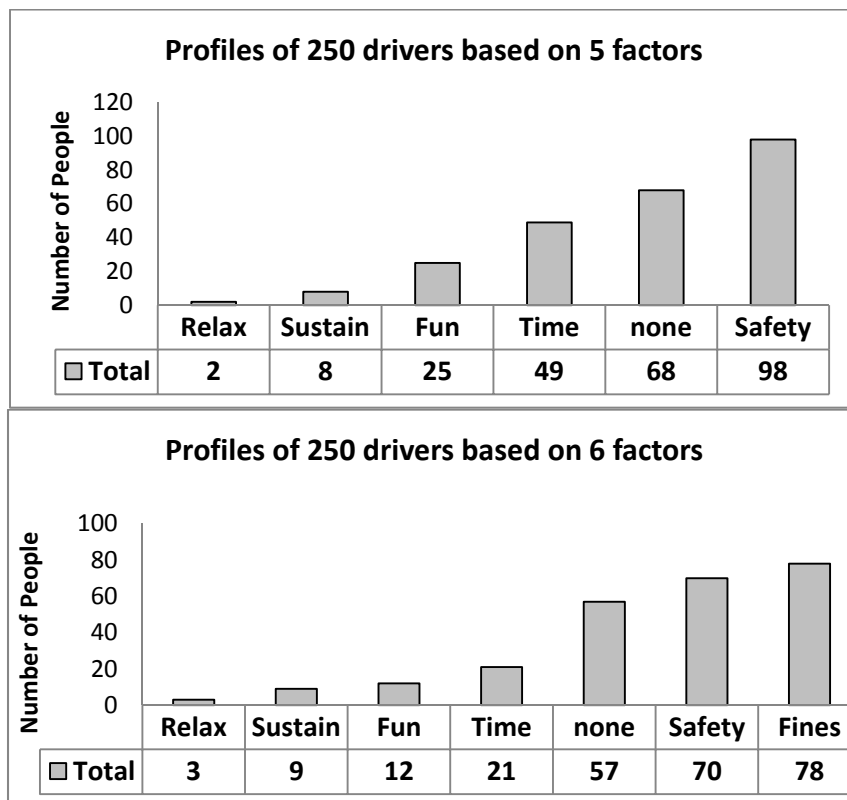


Figure 7.4. Persuasion profiles of respondents across 5-factor and 6-factor calculations

The distribution of profiles based on 6-factor profiles grouped by age, purpose of driving, and frequency of driving is shown by Figure 7.5 (excluding the drivers that did not exhibit any profiles). The age distribution shows that the Fun factor is not important for young drivers. Most young respondents (under 25 years old) were sensitive to the Fines factor, while in the older age group the Safety factor was more important. While the purpose of driving does not differentiate profiles, the frequency of driving shows a difference. Respondents who drove regularly were more sensitive to Fines.

The distribution between male and female respondents was largely unbalanced, so we did not have female respondents exhibiting Relax and Fun profiles. However, there was a small gender effect based on the 6-factor questionnaire responses. There were more male respondents who were sensitive to Fines ($N=64$) than those who were sensitive to Safety ($N=47$), and vice versa more female respondents who were sensitive to Safety ($N=23$) than those who were sensitive to Fines ($N=14$).

The analysis of PDV per age group, gender, purpose, and frequency of driving is useful for understanding implications for the recruitment of participants for the driving experiment in Chapter 8. Recruiting only young male drivers and recruiting only regular drivers may lead to having more participants who are sensitive to monetary messages.

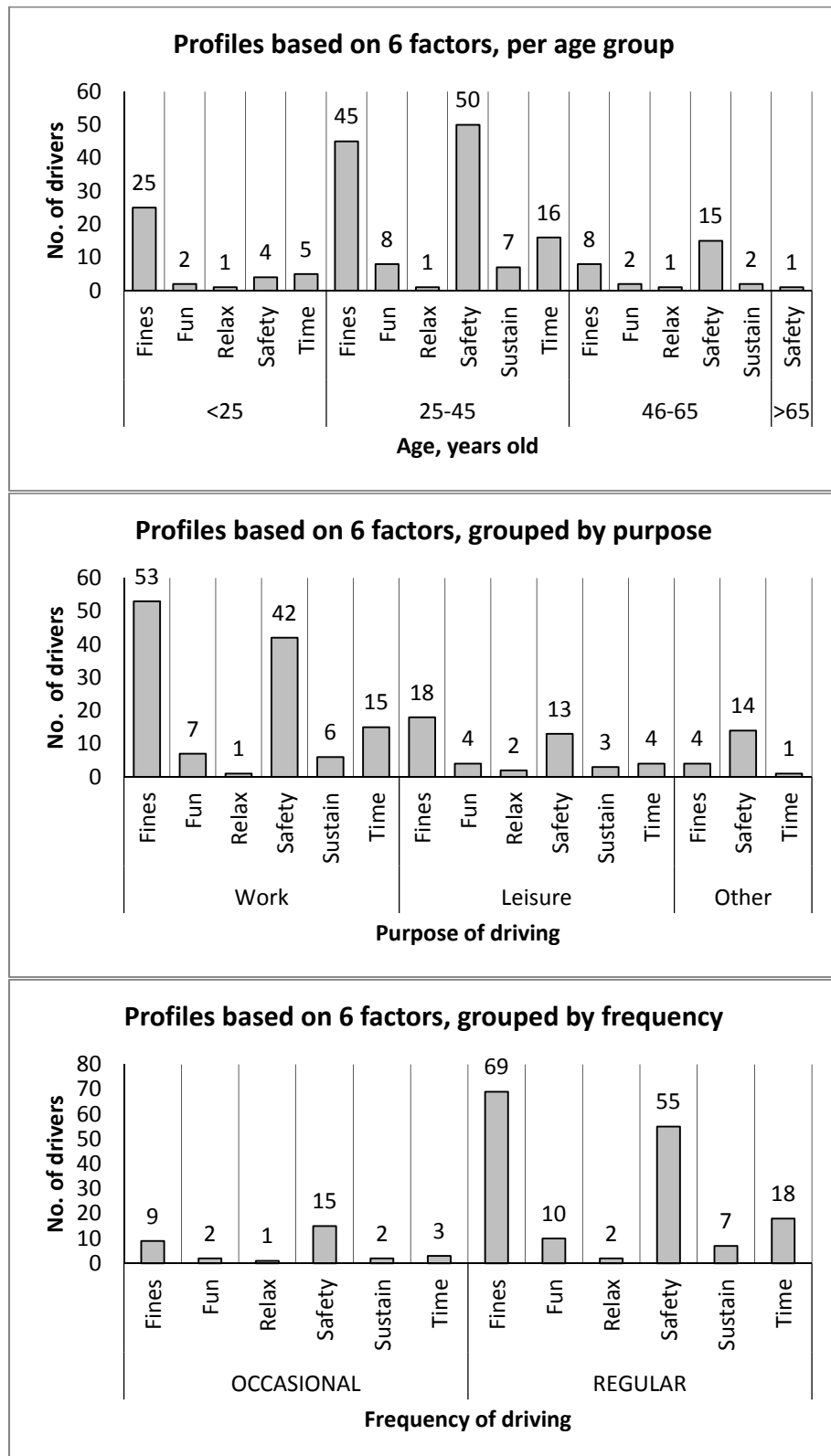


Figure 7.5. Persuasion profiles of respondents categorized by age groups, purpose of driving, and frequency of driving

7.6. Conclusion

The result of the PDV questionnaire confirmed that drivers have different reasons underlying their behaviors. The different reasons can be categorized into five personal values in driving: Sustainability, Fun, Relax, Safety, and Time. The result also confirmed that monetary-related messages are important in traffic, as indicated by the high number of drivers exhibiting Fines profiles. The final questionnaire (25 items) can be used for finding drivers who are also sensitive to traffic fines. In the case of no interest in traffic fines related behavior, the questionnaire can be administered with only 22 items without changing the structure of the factors.

This chapter has described the construction of the Personal Driving Values Questionnaire. The final questionnaire is to be used for establishing persuasion profiles before using persuasive CSA, so that CSA can support the different motivations of drivers.

A driving experiment is to be conducted in order to confirm whether this motivation support is effective. The effectiveness of the motivation support is determined by whether the motivation support can persuade drivers to join and stay in a platoon. The method is to let drivers use CSA for an extended period of time. The PDV questionnaire is to be administered before the experiment, and the result is used for the driving experiment.

8

Evaluating Behavior Change using a Serious Game Experiment

This chapter presents an experiment on persuading drivers to follow and stay in platoons of cooperative vehicles by means of messages relating to their personal driving values. The personal driving values are the five factors extracted from the 22-item Personal Driving Value Questionnaire (PDV-Q). The experiment aimed to test the main hypothesis: the persuasive messages that are compatible with a driver's persuasion profile strengthen the driver's compliance with speed advice. The driver's persuasion profile can be determined in two ways: 1) on the basis of their PDV-Q responses (subjective measurement); 2) on the basis of their driving behavior (objective measurement). The antecedent hypothesis is that people are already compliant with speed advice without having to be influenced by persuasive messages. The subsequent hypothesis is that people can be persuaded by messages offering monetary rewards. To observe driver's behavior change, the driving experiment was conducted over an extended period. In order to overcome the limitations of using a driving simulator for conducting such an experiment, a multi-level game scenario was developed. In the experiment, participants were selected using the PDV-Q and came to three sessions, each on a different day, where they played three levels of the game in each session. Their behavioral responses to persuasive messages were measured. The last level of the game was a bonus level where they could ignore the game rules while driving with an Adaptive Cruise Control (ACC) system. In the post-interviews, participants were asked to rate the acceptance of Cooperative Speed Assistance (CSA) as an assistant for cooperative driving. At the end of the game, they were asked again to fill in the PDV-Q. The results of the experiment show that the speed advice alone can already change people's behavior toward participation in cooperative driving. It was found that the effectiveness of persuasive messages was not stronger than the effectiveness of speed advice only. It was also found that monetary messages might still be effective enough for supporting behavior change of people who disregard non-monetary messages. Finally, the results also indicate that ACC may serve as an additional ability support for persuading drivers to participate in cooperative driving. The implications of using serious games and driving simulators for testing persuasive technology in the driving context are discussed.

8.1. Introduction

The cooperative driving behavior to be studied in this chapter consists of driving behind a platoon of vehicles and adapting speed in order to join and stay with the platoon. First of all, platoons of cooperative vehicles drive in one dedicated lane. If a platoon drives in the right lane, then the driver's preference for the right lane represents the platoon following behavior. Secondly, vehicles in a cooperative driving platoon have their speeds coordinated with each other. Drivers are assisted by Cooperative Speed Assistance (CSA), informing them about the required speed for joining a platoon. Complying with the speed advice of CSA is a condition for platoon following behavior. As reviewed in Section 6.1, drivers are reluctant to slow down toward the advised speed for a number of different reasons. Therefore, we are interested in looking at the effect of persuasion strategy for influencing drivers to engage in cooperative driving where the advised speed is lower than the current speed.

The concept of CSA as a behavior change support system is presented in Chapter 6, where CSA provides supports for increasing driver's ability, driver's opportunity, and driver's motivation to comply with an advice. Ability refers to the driver's ability to change speed according to the advice. Opportunity refers to the right moment to adjust the speed in relation to the vehicle's situation among other vehicles in the traffic. Motivation is associated with the driver's personal decision to follow an advice or not. To increase driver's motivation to comply with an advice, CSA is displays persuasive messages to drivers.

In order to test whether persuasive messages can be used for influencing drivers to engage in cooperative driving, the notion of a persuasion profile is used. The persuasion profile of a driver determines which persuasion strategy the driver is expected to be most susceptible to. Personally relevant values as the targets for the different persuasion strategies are discussed in Chapter 6. The strongest personal driving value of a driver characterizes the driver's persuasion profile, as discussed in Chapter 7. The non-monetary personal driving values identified among drivers are Sustainability, Fun, Relax, Safety, and Time.

As stated at the end of Chapter 7, an extended period of driving is needed for observing driver's behavior change while using CSA. Attaching CSA to a Portable Navigation Device (PND) and testing in a driving test participant's car was not possible due to the unavailability of cars with the required technology as well as the facilities needed for setting up cooperative driving scenarios. Therefore, conducting the driving experiment in a medium-fidelity driving simulator was chosen as an alternative option.

In previous experiments, we noticed that people who accepted participation in experiments on CSA brought a high motivation for showing their skills in responding to messages displayed by CSA. This was shown by the high compliance rate in following CSA advice as indicated by the previous experiments (Chapters 2, 3, 4). It was not a problem in experiments aimed at evaluating the user interface design, but it would be a problem in an experiment for evaluating the compliance itself. Reframing the experiment as a game may temper the aforementioned motivation. Using a game, it is expected that participants will be more motivated toward winning the game or collecting game points instead of being motivated to comply with each advice. In other words, taking the serious game approach is advantageous in terms of hiding the goal of the experiment. This approach can also solve the problem of participation bias or demand characteristics (Intons-Peterson, 1983), where participants guess and try to meet the experimenter's expectation.

Another advantage of using a game approach is the possibility of creating scenarios that resemble real life situations. In everyday life, the willingness to comply with speed limits may be overruled by other real life goals (habits, time pressure, etc). Using the serious game approach, we can induce similar alternative/competing goals.

The use of a driving simulator is not optimal for a long-term behavior study, because of the relatively short behavior observation period. Therefore, a serious game is designed which consists of multiple levels, to facilitate extended interaction with the driving simulator. In the game, players drive with a PND that has CSA functions and they encounter platoons to join and interact with. Additionally, all of the other traffic rules (including traffic fines and the new concept of reverse fines as evaluated in Chapter 6) are designed to be realistic (i.e. exist in the real world, not only in the game).

This chapter starts with formulating hypotheses and the testing plan in Section 8.2. Then Section 8.3 follows with the description of the game design to be used in the driving simulator experiment. The driving simulator experiment using the serious game is outlined in Section 8.4, and its results are presented in Section 8.5 (subjective results) and 8.6 (objective results). The chapter ends with a conclusion and a discussion of the findings and their relation to the hypotheses, concluding the study on using CSA as a behavior change support system.

8.2. Hypotheses

8.2.1. Formulation

In order to test whether a strategy tuned to a driver's persuasion profile leads to a better behavior than a one-size-fits-all persuasion strategy, the CSA prototype was designed to display different persuasive messages. These messages are displayed

with each Slow Down advice, aiming to persuade drivers to slow down. It is assumed that the driver's tendency to follow a platoon and/or to slow down is enhanced by messages representing the persuasion strategy matching the driver's persuasion profile. These messages are considered the compatible messages to his/her persuasion profile.

Our main interest is to find whether compatible persuasive messages are indeed increasing the driver's compliance with speed advice. We need to check, however, whether the driver's compliance is simply due to the speed advice as such, and not to the messages related to their persuasion profile. Therefore, hypothesis H1 is that drivers are already compliant with speed advice. Subsequently, we would like to test whether the driver's compliance with speed advice is increased upon receiving persuasive messages matching their persuasion profiles.

The increase in driver's compliance with speed advice accompanied by persuasive messages is used as an indicator that the persuasive messages are effective. Therefore, the next hypothesis (H2) is that compatible persuasive messages strengthen the compliance with speed advice, where the compatibility is different across drivers, as indicated by the notion of persuasion profile.

The next question then is how to determine a driver's persuasion profile. A previous study (Kaptein et al., 2012) used a questionnaire to determine the persuasion profile of experiment participants. Similarly we use a questionnaire (self-report persuasion profile), but we also use objective measurements for determining a participant's persuasion profile (behavioral persuasion profile).

With respect to the self-report persuasion profile, personal driving values are measured by the Personal Driving Value Questionnaire (PDV-Q) as discussed in Chapter 7. It is assumed that personal driving values are the determinant of the driver's responses toward persuasive messages. Therefore, the sub-hypothesis (H2a) is that the persuasion profile can be determined on the basis of the driver's response to PDV-Q.

With respect to the behavioral persuasion profile, personal driving values are measured by observing driver's compliance with speed advice. It is assumed that if a message representing a particular persuasion strategy can increase the driver's compliance with speed advice, then the message is related to the driver's personal driving values. Therefore, the alternative sub-hypothesis (H2b) is that the persuasion profiles can be determined on the basis of the driver's compliance with persuasive messages representing a particular persuasion strategy.

Our theory emphasizes the use of non-monetary messages as based on personal driving values for persuading people to comply with CSA. However, as reviewed in Chapter 6, several studies reported that people put a high value on monetary rewards in ITS applications. This is supported by the finding in Chapter 7 about Fines as one of the six personal driving values. Therefore, the last hypothesis (H3) is that drivers can be persuaded by monetary messages. A summary of the hypotheses is as follows.

- H1: Speed advice influences drivers' speeding behavior and increases the likelihood that they join a platoon, compared to a baseline situation without speed advice.
- H2: Persuasive messages that are compatible with a driver's persuasion profile strengthen the drivers' compliance with speed advice, compared to a speed advice only condition.
- H2a: The driver's persuasion profile as mentioned in H2 can be determined on the basis of the driver's PDV-Q scores.
- H2b: The driver's persuasion profile as mentioned in H2 can be determined on the basis of the driver's behavioral response to persuasive messages.
- H3: Monetary rewards strengthen drivers' compliance with speed advice, compared to a speed advice only condition.

8.2.2. Testing

To test the hypotheses, a testing plan is proposed. This section outlines the experiment design (see Section 8.4.2). There are five stages: participants sign-up, Phase 1, Phase 2, Phase 3, and Phase 4. When participants sign up, the PDV-Q is administered. In Phase 1, participants' baseline driving behavior is measured. In Phase 2, participants' response to speed advice is measured. In Phase 3, participants continue to receive speed advice and in addition they receive non-monetary persuasive messages. In Phase 4, participants are divided into two groups: 1) speed advice + non-monetary persuasive messages; 2) speed advice + monetary persuasive messages.

Participants Sign-Up

Goal: To identify participants' subjective persuasion profile (through PDV-Q).

Participants are required to have driving experience of at least 1.5 years.

Task: The 22-item (5 factors) questionnaire is administered as early as possible in order to reduce the possibility of participants remembering the contents of the questionnaire and relating them to the persuasive messages during the experiment.

Demographics: Age, gender.

Metrics: Only participants with a strong profile are selected. A participant with a strong profile means that he/she scores high on a single factor from the driving value questionnaire. It does not matter whether for instance we only have participants with

Safety and Fun profiles only. What is more important is that we can run the experiment with different non-monetary profiles of drivers.

Intended result: List of participants invited to the driving simulator experiment.

Experiment Phase 1: Baseline (Levels 1, 2)

Goal: To measure participants' baseline behavior.

Task: Participants are required to play a driving game of 2 levels. In the first level, participants are expected to learn about the existence of platoons in the right lane. If they encounter a platoon, they can either join the platoon or overtake it. In the second level, they always face a traffic jam in the left lane after they overtake a platoon, and they never face a traffic jam if they follow platoons. They are expected to learn the consequences of not following platoons.

Metrics: Participants' behavioral response to each slowing down platoon is recorded. The behavioral response consists of speed response and lane preference. The speed response is the rate of change of participant's speed toward the advised speed. The lane preference is the choice of lane and the time they spend behind platoons. Driving in the right lane means they follow a platoon.

Intended result: Participants understand platooning and the consequences of joining or overtaking a platoon.

Experiment Phase 2: Speed Advice (Levels 3, 4)

Goal: To measure participants' behavior toward speed advice.

Task: Participants are required to continue the driving game for 2 more levels. They receive Slow Down and Speed Up advices in relation to the platoon's speed. In the third level, they receive the speed advice only when they are in the right lane (behind a platoon). In the fourth level, they receive the speed advice on both lanes.

Metrics: Participants' behavioral response to each speed advice is recorded (as recorded in Phase 1). The speed response and the lane preference are compared with the baseline behavior in order to determine the effectiveness of the speed advice. The increased compliance with speed advice is determined by a faster rate of change toward advised speed as well as more right lane preference.

Intended result: Participants understand the different speed advices for following platoons. If participants have the same/worse compliance with the advice as compared to the baseline, then H1 fails. Otherwise, H1 succeeds.

Experiment Phase 3: Speed Advice + Persuasive Messages (Levels 5, 6)

Goal: To find participants' objective persuasion profile and to evaluate participant's subjective persuasion profile.

Task: Participants are required to continue the driving game for 2 more levels. In each game level, participants receive all 5 non-monetary messages: Sustainability, Fun, Relax, Safety, and Time. The messages are presented randomly. They accompany Slow Down advices. There is no difference in the given advices between Level 5 and Level 6.

Metrics: At each message presentation, participants' behavioral response to the speed advice is recorded (as in Phase 1 and Phase 2). The speed response and the lane preference are compared with the baseline behavior and the behavior in Phase 2 in order to determine the effectiveness of the persuasive messages. The behavior is also compared with participants' PDV-Q response in order to evaluate the predictive power of the persuasion profile as determined by PDV-Q.

Intended result: If participants have the same/worse compliance with the advice as compared to Phase 2, then H2 fails. Depending on the compliance measure, H2a and H2b are evaluated separately. H2a regards compliance according to PDV-Q (subjective), H2b regards compliance according to behavioral response (objective). If participants have a better compliance with persuasive messages that are compatible with their persuasion profile as compared to Phase 2, H2 succeeds. Then, it needs to be established whether H2a or H2b is confirmed.

Experiment Phase 4: Compatible vs. Incompatible Messages (Levels 7, 8)

Goal: To find whether participants' behavior according to persuasion profile is persistent and to find the effectiveness of monetary messages.

Task: Participants are required to continue the driving game for another 2 levels. In each game level, half of the participants receive non-monetary messages according to the result of Phase 3, and another half of the participants receive monetary messages. There is no difference in the given advices between Level 7 and Level 8.

Metrics: At each message presentation, participants' behavioral response to the speed advice is recorded. The speed response and the lane preference are compared with the baseline behavior as well as the behavior in Phase 2 and Phase 3 in order to determine the effectiveness of the persuasive messages. The two groups are compared with each other in order to find which group has a better compliance with the messages. The changes in compliance from Phase 3 to Phase 4 are also computed for each group.

Intended result: H2 is reevaluated to assess the sustainability of the behavioral change depending on the result in Phase 3. If the group with non-monetary messages has a better compliance with the advice as compared to Phase 2, and the effective persuasive messages are the same as in Phase 3, then it follows that the behavioral change is sustainable. Otherwise, H2 fails. If the group with monetary messages has a better compliance with the advice as compared to Phase 2, then H3 succeeds. Otherwise, H3 fails.

8.3. Game Design

8.3.1. Fantasy, Sensory Stimuli, Control

According to a literature review on different game dimensions (Garris, Ahlers, & Driskell, 2002), a game has the following characteristics: fantasy, rules/goals, sensory stimuli, challenge, mystery, and control. It is clear that the driving simulator already

provides sensory stimuli, due to 3D graphics used in the simulation. It is also clear that the driving simulator already provides control for a game experience, as facilitated by the steering wheel, pedals, and other controls as found in real cars. The fantasy, rules/goals, challenge, and mystery have to be designed. To create a fantasy, a story that separates the game from the real world has to be built.

Cooperative driving is a new concept, therefore it creates an opportunity to utilize fantasy to introduce this new concept to potential users. A brainstorm was conducted with four designers in a workshop on serious games for cooperative driving in order to come up with the fantasy concept. The concept of a mother duck and her ducklings was developed to represent a platoon of vehicles. As shown in Figure 8.1, the symbol to represent a member of a vehicle platoon is a simple icon of a duck seen from the back, because approaching a platoon means looking at the platoon of vehicles from behind.



Figure 8.1. The concept of ducklings, represented by a duckling icon seen from its back

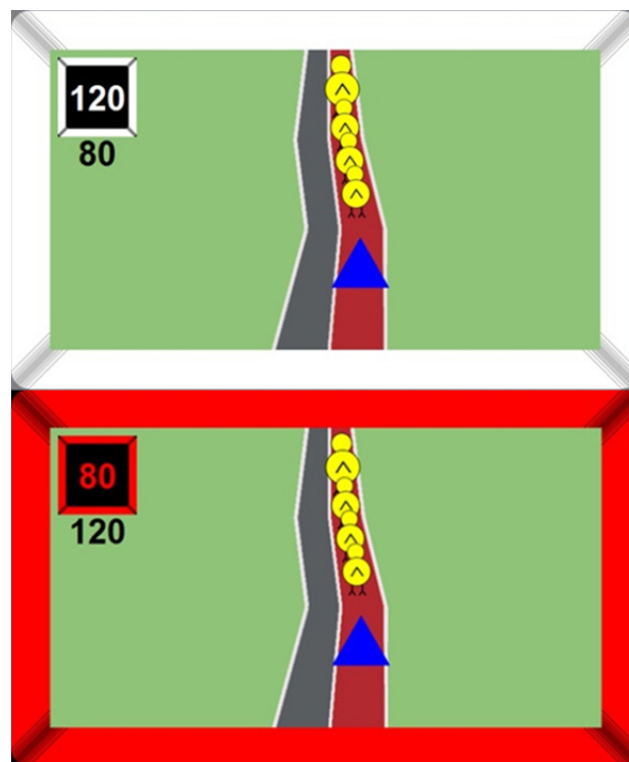


Figure 8.2. Above: Speed Up advice; Bottom: Slow Down advice;
Both: the sequence of ducklings represents a platoon of vehicles ahead

The functional requirement of combining CSA with a PND, where drivers can detect platoons through their PND screens, was realized by showing a duckling sign on a PND screen. Combining the navigational information (see Figure 5.3 on page 87) with the duckling concept for the platoon indication resulted in the user interface design as shown in Figure 8.2 above. The visual user interface is linked to the driving simulator, where the sequence of ducklings corresponds to a platoon of vehicles in the simulation.

An auditory alert created from a sound recording of ducklings was used in order to alert the driver of a platoon 6.5 seconds before encountering the platoon. This way, drivers are aware of an upcoming platoon without having to look at their PND screen. The use of the ducklings sound was intended to enhance the fantasy characteristic of the game. The fantasy is: there are ducks/ducklings on the highway.

8.3.2. Rules/Goals, Challenge, Mystery

“Highway 2020: Follow the Ducks, Reach your Destination!” is the title of the game. In the game, players drive in a future interconnected highway and are directed by the navigational system in order to reach a destination. The game consists of 8 levels, where Levels 1-2 are played in Phase 1 of the experiment, Levels 3-4 are played in Phase 2 of the experiment, Levels 5-6 are played in Phase 3 of the experiment, and Level 7-8 are played in Phase 4 of the experiment, as outlined in Section 8.2.2. The persuasive messages displayed by CSA are called “messages from the ducks”.

To address hypothesis H3 about the effectiveness of monetary messages for persuasion, the monetary messages should be real. Players are presented by an amount of money (30 Euro) at the beginning of the experiment, which they can increase or decrease during the course of the experiment. Players only receive the final amount at the end of the experiment (when they finish all game levels), which is intended as an influence to keep them in the experiment until the end.

The main rules of the game:

- The left lane is the overtaking lane, and the right lane is where the ducks are. Players are free to decide whether they will follow the ducks (trying cooperative driving) or not.
- Players have to stay in the right lane as much as possible, unless overtaking.

The main goal of the game is that players have to reach the destination to complete a game level in as little time as possible. At the end of each level, a time bonus is presented to players, and noted on a whiteboard in the game room, for each player to see and compare with other players. The winner, who is the one with the most time bonus, is promised a gift at the end of the game. The challenges to reach this goal are

how to avoid losing money and how to gain money that counts toward the amount of money at the end of the game:

- A traffic fine applies when exceeding the 120km/h speed limit. If players exceed the speed limit and are caught by a speed camera, they get a small traffic fine (10 cents).
- When accidents occur, participants face real-life consequences: losing time and money. In the simulator, a crash costs a few seconds to show a replay, reducing the time bonus. In the context of the game, players can lose a lot of money (1 Euro) in case of an accident.
- For players who receive monetary-messages, following the ducks while receiving the persuasive message causes them to gain 20 cents, which is a reverse (but double) of the traffic fine. This double value of the traffic fine is meant to make the message more appealing to players, especially if they already lose money and would like to keep the amount of money they receive at the end of the game.

The rules, goals, and challenges of the game are designed to be as similar as possible to real-life highway driving. Guided by the element of mystery, combined with the fantasy of the ducks, we designed the game so players find the ducks mysterious and get curious about their behavior. Players may get curious by finding answers to “What do I get if I don’t follow the ducks?”, “What do I get if I always follow the ducks?”, “What actually are these ducks doing?”, “Why are the ducks giving me these messages?”, “Can I hide from the speed camera?”, “How can I overtake the ducks when the left lane is full of traffic?”, “Can I break other traffic rules and not lose money?”.

8.3.3. Persuasive Message Design

The CSA user interface needs to display the persuasive messages as required by the analysis in Section 8.2. There are two ways of influencing drivers according to their sensitivity: positive or negative. Positive messages remind drivers that they are satisfying their personal values by complying with the speed limit. Negative messages warn drivers that they will not satisfy their personal driving values if they do not comply with the speed limit.

We use positive persuasion, because:

- In terms of product image, people will not use CSA if it brings them negative consequences
- Positive messages trigger people’s curiosity as suggested by the literature on curiosity and intrinsic motivation (Kashdan & Fincham, 2004; Loewenstein, 1994)
- Positive messages are less likely to induce reactance⁸ (Roubroeks, Ham, & Midden, 2010)

⁸ Reactance occurs when people feel pressured to change their attitude/behavior, so they strengthen their existing attitude/behavior instead.

For experiment Phase 1, CSA provides messages from 5 persuasion strategies: Sustainability, Fun, Relax, Safety, and Time. For experiment Phase 2, CSA provides messages from an additional persuasion strategy: Money.

Table 8.1 shows the message for each persuasion strategy. Auditory signals or speech are not used for expressing these messages, since they may be annoying (see Chapters 2 and 3). Instead, visual cues are used to represent these messages.

Table 8.1. Persuasive messages as explained in sentences

Strategy	Messages
Sustainability	If you comply with the speed limit, you contribute less pollution to the environment
Fun	If you comply with the speed limit, you will experience more fun in your trip (saved from traffic jam, etc)
Relax	If you comply with the speed limit, your driving will be more relaxed
Safety	If you comply with the speed limit, your driving will be safer
Time	If you comply with the speed limit, you will save time
Money	If you comply with the speed limit, you will earn money

The visual cues representing the persuasive messages require good glanceability (see Chapter 5). Therefore, the design and evaluation of the visual cues were conducted using recommendations from a study on glanceable icons (Matthews, 2007). The recommendations are based on the investigation of primary task error time (the time spent looking away from the main display), peripheral processing time (the time from the change occurring on peripheral display until the user's first look at the display), and user's reaction time to take action upon the change on the peripheral display. The investigation explored both high and low symbolism icons, and both complex and simple visual rendition (see Figure 8.3 for examples).

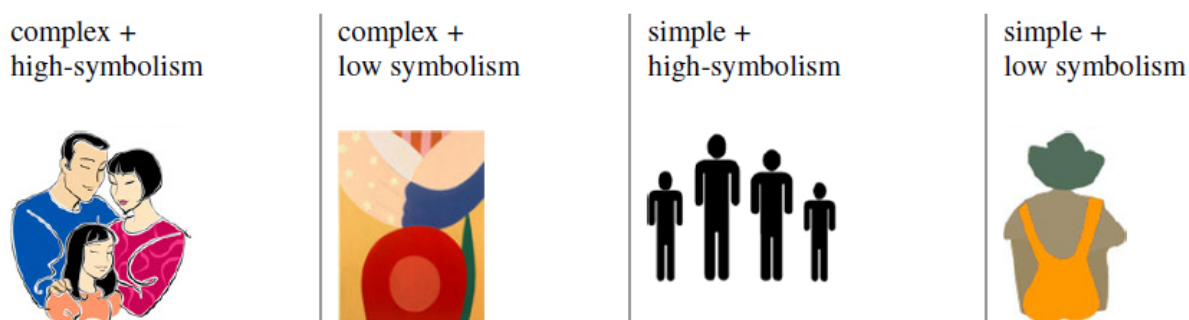




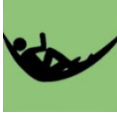









Figure 8.3. Examples of a “family” icon represented in high and low symbolism, complex and simple rendition (Matthews, 2007) pp.125

Matthews found that there was no difference in reaction time between low symbolism icons and high symbolism icons, but she advised not to use low symbolism for a larger set of icons. As symbolism increases, both peripheral processing time and primary task error time decreases. We successfully tested (see

Chapter 5) that the use of low symbolism (colors: white – black – red) is appropriate for the three states of the speed advice (Too Slow – Appropriate – Too Fast). Adopting the findings by Matthews, it is more appropriate to use high symbolism for a larger set of icons. Therefore, the six persuasive messages were designed as high symbolism icons. Matthews also reported that there was no difference in reaction time between simple rendition and complex rendition, although it was suggested that complex rendition may gain better approval. Therefore, two set of icons (both simple and complex renditions) were created to be tested with people. A third set (text) was also created for the test, because textual information does not require learning.

Table 8.2. Icon tests based on category: Test 1 (simple rendition), Test 2 (complex rendition), Test 3 (textual).⁹

Test 1		Test 2		Test 3	
ECO	→ 	ECO		ECO	eco
FUN	→ 	FUN		FUN	fun!
RELAX		RELAX → 		RELAX	relax
SAFE		SAFE → 		SAFE	safe
TIME		TIME		TIME →	-5 minute
MONEY		MONEY		MONEY →	+20c €

The three sets of icons were tested for glanceability. Because drivers will be able to learn these icons before using CSA in their cars, the goal of the test is for correct recall of the meaning of the icons while driving. Six interaction designers were invited to participate in the icon tests. Test 1 was about simple icons, Test 2 was about complex icons, and Test 3 was about textual icons. The procedure was as follows:

⁹ Test1-Fun was taken from (Public Domain, 2007), Test1-Relax was modified from 'Park and Read' icon in American public libraries, Test2-Fun was taken from a photograph of a famous racing driver Michael Schumacher, and Test2-Relax was taken from (Facesgroup, 2012).

1. Before each test, each participant was shown the six icons in the set and its textual description, as shown in Table 8.2.
2. During each test, the six icons were presented randomly and the participants were asked to recall the textual representation of the icon and say it while driving.
3. At the end of the three tests, each participant was presented with a choice card and asked to choose the most preferred icon. The judgment and the motivation of the icon preference were discussed in relation to the messages in Table 8.1. The chosen icons by participants are indicated in Table 8.2 by an arrow next to each chosen icon.

The participants could recall the icons quickly while driving, with no noticeable difficulties. Both the simple icon of FUN and the complex icon of SAFE received approval from all six of them. These icons were preferred, because the complex icon of FUN and the simple icon of SAFE were considered unclear and ambiguous. The textual icons for both TIME and MONEY were approved strongly by 4 participants each, because it was considered important to know the actual values of time gained and money saved. The simple icon for ECO and the complex icon for RELAX were approved by 3 participants each, which was highest compared to other icons, which received a smaller number of approvals.

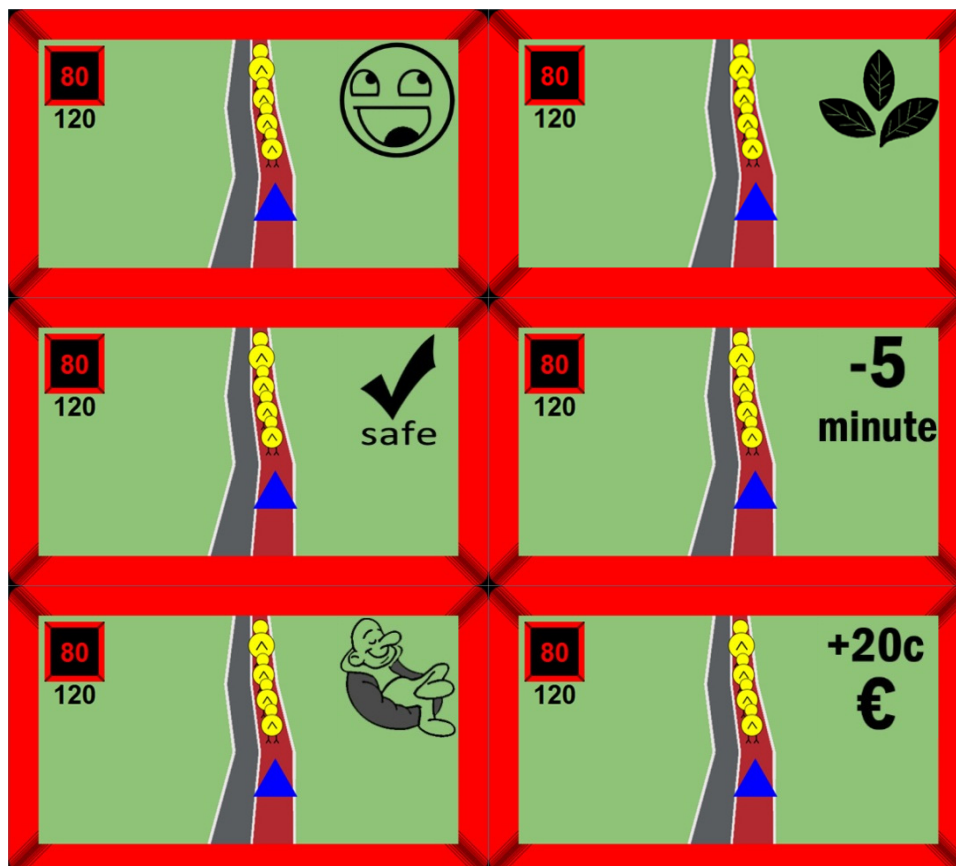


Figure 8.4. Persuasive messages represented with icons displayed on a Slow Down advice. Left: Fun, Safety, Relax; Right: Sustainability, Time, Money

After the symbolism tests, the visual representations of the persuasive messages were implemented in the CSA display for Slow Down advice. Figure 8.4 shows the six persuasive messages displayed on an 80 km/h speed advice with 120 km/h current speed. The details of the CSA user interface design can be found in Chapter 5.

8.4. Experiment Setup

8.4.1. Participants

Participants were invited to the driving game through mailing lists of international students, industrial design students, and automotive technology students. Invitation posters with a phone number to SMS their email address and a QR-code directing to a participation website were distributed in some buildings of the university. The invitation contained a link to fill in the 22-item PDV-Q. Participants were informed that the questionnaire was used as a basis for deciding their eligibility to participate in the game. They were instructed to wait for an invitation to play the game, or, if not invited, to receive a ten Euro reward (one winner out of a draw) for their questionnaire participation. The invitation was responded by 56 people.

In order to find participants' profiles, for each participant a standardization is done on the basis of his/her response to the whole PDV-Q, as explained in the previous chapter (Section 7.5). This method resulted in only 27 eligible people out of the 56 respondents. This is too few for the invitation, as we had to invite more people than needed for the experiment (saving for declined invitations). Therefore, another criterion for eligibility was set by determining whether a respondent had extreme scores regarding his/her personal driving values. The respondents with both ≤ 3 and ≥ 5 scores (e.g. 2 for Safety and 5.5 for Time) on their profiles were also considered eligible to participate in the driving game. An additional 11 people met this eligibility criterion to participate in the driving game. In total 38 people were invited to the game.

From the 38 people, 30 people answered the invitation. One participant dropped out before playing the game, and another dropped out in the first session. In total, 28 participants (6 female, 22 male, age 20-29 $M=23.25$) played the game until the end. The profile distribution based on PDV-Q is as follows: 20 Safety, 5 Time, 2 Fun, 1 Relax. None of them exhibited a Sustainability profile. The list of their profiles can be seen in Appendix E.1.

Evaluating the questionnaire using exploratory factor analysis (as in Chapter 7) needs a lot of respondents, but we can perform an evaluation by comparing the result of the 28 participants with the result of the 250 respondents presented in Section 7.5. For the 28 participants, Pearson's correlation analysis between scores on the different dimensions of PDV-Q resulted in a Safety-Relax correlation of $r=.446$

($p=.017$), a Safety-Sustain correlation of $r=.550$ ($p=.002$), a Fun-Time correlation of $r=.542$ ($p=.003$), and a Relax-Fun negative correlation of $r=-.480$ ($p=.010$). This result is similar to the average of 250 respondents in Section 7.5, where Safety-Sustain-Relax are correlated, and Fun-Time are correlated. However, the Cronbach's Alpha values per profile are not akin to the Alpha values from the 250 respondents (presented in Section 7.4), especially for Safety. For the 28 participants, the Cronbach's Alpha values are .786 for Sustainability, .839 for Fun, .587 for Relax, -.278 for Safety, and .755 for Time. The Alpha value for Safety is very low, indicating a low correlation between items. All participants scored high (at least 4.75 out of 7), therefore this low correlation is a result of the narrow distribution of scores. For the experiment, we nevertheless used the Safety scores for determining persuasion profile as well (with a probability of the score not representing a participant's strongest value).

8.4.2. Design

Due to time limitations (limited availability of the driving simulator), it was not possible to execute each game level on a separate day. Instead, playing the game was distributed over three separate days. Since the game consists of eight levels and in addition a post-interview and questionnaire were planned to be administered at the end of the game, the execution of the levels was distributed as follows: Levels 1-2-3 on the first session, Levels 4-5-6 on the second session, Levels 7-8 on the third session. The relationship between Phases, Levels, and Sessions is explained in Figure 8.5.

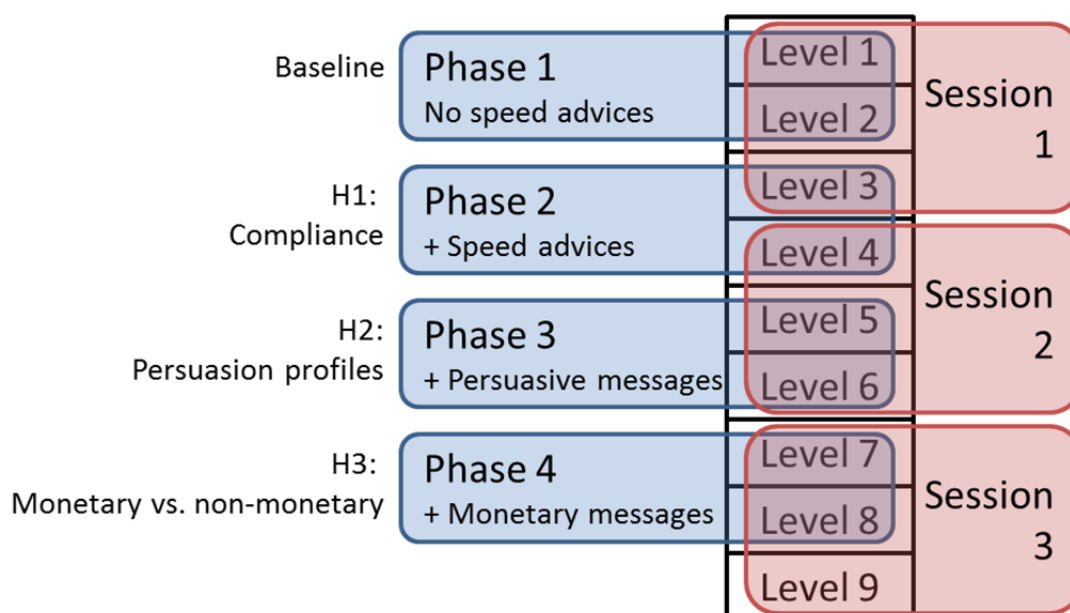


Figure 8.5. Nine game levels distributed over three sessions. Hypotheses testing through Phase1, Phase2, Phase3, Phase4. Experiment conditions are changed incrementally from Phase1 to Phase4.

Due to some extra time left in the third session, a bonus level (Level 9) was added at the end. It was an opportunity to assess participants' attitude toward Adaptive

Cruise Control (ACC). Evaluating the ACC experience is not part of the hypotheses testing, but it is part of evaluating the ability support of CSA. This evaluation can provide insights on supporting behavior change in cooperative driving across the motivation – ability – opportunity framework (see Section 6.2).

Participants were asked to schedule the first and second sessions with at least a day in between. All 28 participants were asked to fill in their schedule of the two sessions over a two-week period. After completing the second session, they were asked to schedule the third session (at least five days after the second session). The experiment was estimated to take three one-hour sessions, or a total of three hours, which was considered appropriate in terms of the reward given to the participants.

The whole experiment took three and a half weeks. The first and second week were used to get all 28 participants to complete up to level 6, i.e. finish up to Phase 3.

In order to divide participants into two groups in Phase 4, the original plan was to use their behavioral response toward persuasive messages in Phase 3. In Phase 4, the participants with better compliance to persuasive messages would continue to receive non-monetary messages, and the participants with worse compliance to persuasive messages would receive monetary messages. The time limitation forced us to adjust the plan for using the behavioral responses of Phase 3 as input for Phase 4. Therefore, a division was made on the basis of the results of the qualitative interviews. The first group consisted of those who subjectively indicated that they were sensitive to persuasive messages. These participants received non-monetary messages in Phase 4 based on their subjective preferences. The second group consisted of those who subjectively indicated that they were not sensitive to persuasive messages. They received monetary messages in Phase 4. As a result of applying this new criterion, in practice there is a possibility of a mismatch between participants' behavioral response and participants' subjective preference.

8.4.3. Procedure

The procedure of the experiment is described in the following paragraphs. In the beginning of the game, participants were introduced to the driving simulator and the navigation system (see Chapter 5 for its design). They also received explanation about the game rules and the story as described in Appendix E.2. The highway track used in this experiment and the different speed limits as followed by the ducks are described in Appendix E.3.

Before the experiment, each participant was asked to sign a consent form assuring the confidentiality of their experiment data and indicating that they could stop the experiment at any time. However, participants were not informed of the following rules:

- If they really had to stop the experiment, then they would get rewards in proportion to the number of levels finished (ethical consideration of allowing participants to stop at any time of the experiment).
- If they lost money in the game, they would get what they lost at the end of the experiment (ethical consideration of paying equal amount in proportion to participant's time in the experiment).

At the end of each session, participants were asked to fill in the in-Game Experience Questionnaire (iGEQ) (Poels, de Kort, & Ijsselsteijn, 2007). It is a 5-point rating scale about the game experience while being in the game, consisting of 14 items. The reason for administering this questionnaire was to create a context for participants that they were really in a gaming experiment.

Session 1 (Phase 1: Levels 1-2, Phase 2: Level 3)

Participants were not required to do a trial drive in order to get familiar with the driving simulator, because the experiment was designed as a game. In a game, typically players jump directly into the game and learn about the game while playing.

In Level 1, participants were asked to directly start driving and mention what they encountered in the game as they drove. Level 1 is a typical highway scenario, where faster vehicles (140 km/h) drive in the left lane, and slower vehicles drive in the right lane (see Table E.4 in Appendix E for the details). The platoons, represented by a sequence of ducks on the PND screen, drove in the right lane.

After completing Level 1, participants were asked whether they were aware of the ducks on the road or not. Because the goal of Level 1 is recognizing the ducks, they were told that the ducks correspond to the cars on the right lane in case they had not already found out.

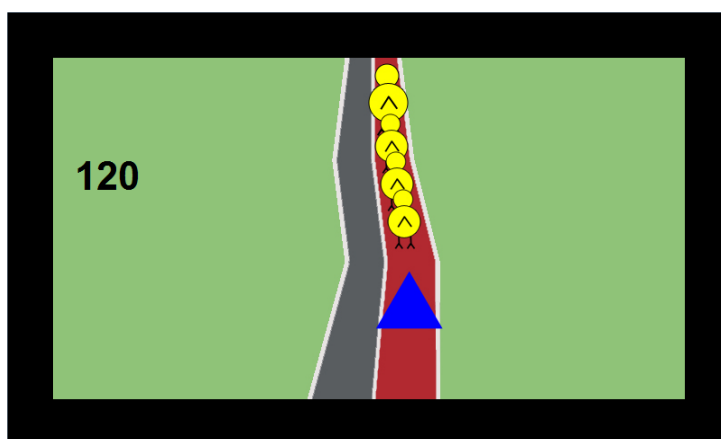


Figure 8.6. CSA interface for Levels 1-2

Participants were prompted to continue the game to Level 2. The traffic condition was similar to that of Level 1, but the traffic on the left lane dropped its speed to 30 km/h when participants overtook the platoons. After completing Level 2, they were asked about the traffic condition with regards to the behavior of left lane traffic. This is a way to reflect on this level compared to the previous level. The user interface of CSA in Level 1 and Level 2 is as in Figure 8.6.

Before going to Level 3, they were told that the system would start giving them dynamic speed limit information. The concept for the speed advice was as designed in Chapter 5 with Too Slow and Too Fast advices, which means that an advice was only displayed when the driver was slower or faster than the speed limit. In Level 3, the speed advice was displayed only when participants were driving in the right lane. After completing Level 3, they were asked whether they noticed the different speed limits through the advice of CSA.

For Level 3 and Level 4, participants received advice through the visual and auditory interface. As described in Chapter 5, the visual interface displayed speed advice, and the auditory interface displayed distance-keeping advice. Combined with the duckling symbol, the visual interface for Level 3 and 4 was as in Figure 8.2.

Session 2 (Phase 2: Level 4, Phase 3: Levels 5-6)

In the beginning of the session, participants were asked whether they still remembered the game rules and received refresher information about the game. They also received a reminder that it was a game in which they were supposed to have fun. The reason of giving this reminder was because at the end of Session 1 it was found that some participants tried to follow the dynamic speed limits faithfully and actually asked whether it was what they were supposed to do.

Starting from Level 4, the speed advice was displayed irrespective of participants' choice of lane where they drove (see Table E.4 in Appendix E for the details). After completing Level 4, participants were asked about the dynamic speed limits and how it differed from Level 3. This is a way of reflecting on this level compared to the previous level in the previous session.

At the beginning of both Level 5 and Level 6, they were presented with messages from the ducks, as if the ducks were speaking to them. The ducks explained the meaning of each icon (Sustainability, Fun, Relax, Safety, and Time), by telling them that they would {contribute to saving the environment / have fun / be relaxed / be safe / save time} if they followed the ducks.

At the end of each level, they were asked to comment on the ducks' messages, and whether they liked it or not, or which one worked for them or not. These qualitative

comments were the subjective results used together with PDV-Q based profiles to determine whether participants were sensitive to certain persuasive messages or not. At the end of the second session, participants were asked again to confirm their preference for persuasive messages.

Session 3 (Phase 4: Levels 7-8, Bonus: Level 9)

Participants came to this session without knowing that they had been divided into two groups. The 12 participants who expressed a dislike for the persuasive messages at the end of Phase 3 (Levels 5 and 6) were given monetary messages. The ducks informed them that they would receive some money if they tried to follow the ducks. This group is labeled the Money group.

The 16 participants who expressed a liking for the persuasive messages are labeled the PM group. They did not receive as many types of persuasive messages as in Session 2. At the end of Session 2, they indicated preferences for Safety (3 people), Safety-Time (10 people) and Relax-Safety (3 people) messages. Therefore, in Session 3 they were given Relax, Safety, and Time messages. Although no one showed a strong Sustainability score in their PDV-Q result, 3 of the 16 PM group participants also indicated a preference for the Sustainability messages. These 3 participants were given Sustainability instead of Relax messages, because they also did not indicate a preference for Relax messages. In total they received Sustainability, Safety, and Time messages.

At the beginning of both Level 7 and Level 8, the Money group was presented with messages from the ducks, explaining that they could receive money if they followed the ducks when the money icon was displayed. The PM group was presented with messages from the ducks containing the same explanation as they received at the beginning of Level 5 and Level 6. At the end of both Level 7 and Level 8, participants were asked to comment on the driving experience as a reflection compared to the previous level. Especially for the first group with monetary messages, they were asked whether they had a better experience because of the monetary messages.

At the beginning of Level 9, they were presented with a message that they got a bonus level, where they could try an ACC system. The experimenter stood next to the participant in order to explain how it worked. The ACC was set to 1.2s time headway (setting from Van den Broek, Ploeg, & Netten (2011)), and turned on from the beginning. The experimenter asked participants to try releasing the accelerator pedal just behind a duckling, to see that the car would really brake by itself, and then move to the left lane behind a faster car, to see that the car would accelerate behind the faster car. After testing this, participants were told to do whatever they wanted by utilizing the ACC, because it was a bonus level. They were also told to finish the game at any time, after they felt they had experienced this level sufficiently.

At the end of this session, after filling in iGEQ participants were asked to answer an additional question on how often they play games: 'Crazy of games!', 'Often', 'Sometimes', 'Rarely', 'Never' (5-point scale). Then, participants spent the remaining time to discuss with the experimenter. Participants were told that the ducks represented cooperative driving and received explanation about the benefits and future applications of cooperative driving. Participants were asked about their general attitude toward cooperative driving. They were asked specifically about the use of monetary benefit and ACC, i.e. "Would you follow cooperative driving if you can receive monetary benefits?" and "Would you follow cooperative driving if you have ACC on?" respectively. They were asked about the persuasive messages and were invited to suggest better messages that would persuade them to follow platoons of cooperative vehicles.

At the end of the game execution, participants were asked to rate the CSA system using a 5-point acceptance scale consisting of 9 items (Van Der Laan et al., 1997) (see Appendix C.1). In addition, they were asked to comment on the visual and auditory interface of CSA (color changes and auditory distance-keeping advice as described in Chapter 5).

The experiment ended with participants filling in the 22-item PDV-Q again. They received the 30 Euro reward. The winner (with the most time bonus) received a chocolate gift.

8.5. Experiment Results – Subjective Measurements

8.5.1. Gaming Behavior

The result of the questionnaire about how often participants play games shows that none of them never play games. Most of them indicated 'Rarely' ($N=7$), 'Sometimes' ($N=11$), and 'Often' ($N=8$). Only two of them indicated 'Crazy of games!'. Spearman's Rho correlation analysis shows that this gaming profile is moderately correlated with their Fun scores ($r_s=.479$, $p=.01$) and Time scores ($r_s=.443$, $p=.018$) from PDV-Q.

Observation of the gaming behavior indicated that some participants ($N=10$) made frequent use of the exit/emergency lane in levels 3 to 8, because the left lane was full of traffic when participants wanted to overtake the ducks. When asked to explain this in the post-interview, participants mentioned that their behavior in the game was different from their behavior in real life, that in real life they would not use the exit/emergency lane to overtake other vehicles. One participant used the left foot to depress the brake pedal, instead of using only the right foot. When asked, he mentioned that it was his usual style in playing driving games in arcade game centers, where there were steering wheel and pedals just like in the driving simulator. Another observation suggests that the speed limit fines somehow prevented

participants from getting very fast in order to win the game. Some participants tested the system and found out that the speed camera would always catch at 130 km/h speed, thus they kept their speed at 129 km/h to be fastest and saved from fines.

Although the duckling concept was intended only for the game, it was useful for introducing platooning concepts to participants. In the post-test interview, participants who never heard about cooperative driving used the “ducks” term to refer to the platoons of cooperative vehicles. No participant indicated dislike for the concept. Instead they had fun with the concept. One of them reported reading about the use of the duckling concept for explaining cooperative driving in a local newspaper.

8.5.2. CSA Acceptance

The results of the Van Der Laan acceptance rating of CSA were on average above 3, where 5 denotes positive values, as shown in Figure 8.7. There was no difference between the Money group and the PM group, except for the Assisting item ($t=-2.042$, $df=26$, $p=.051$). The Money group ($N=12$) rated Assisting at 3.83, and the PM group ($N=16$) rated Assisting at 4.44. This may imply that by using different messages (instead of only monetary ones), CSA was considered as more assisting by participants.

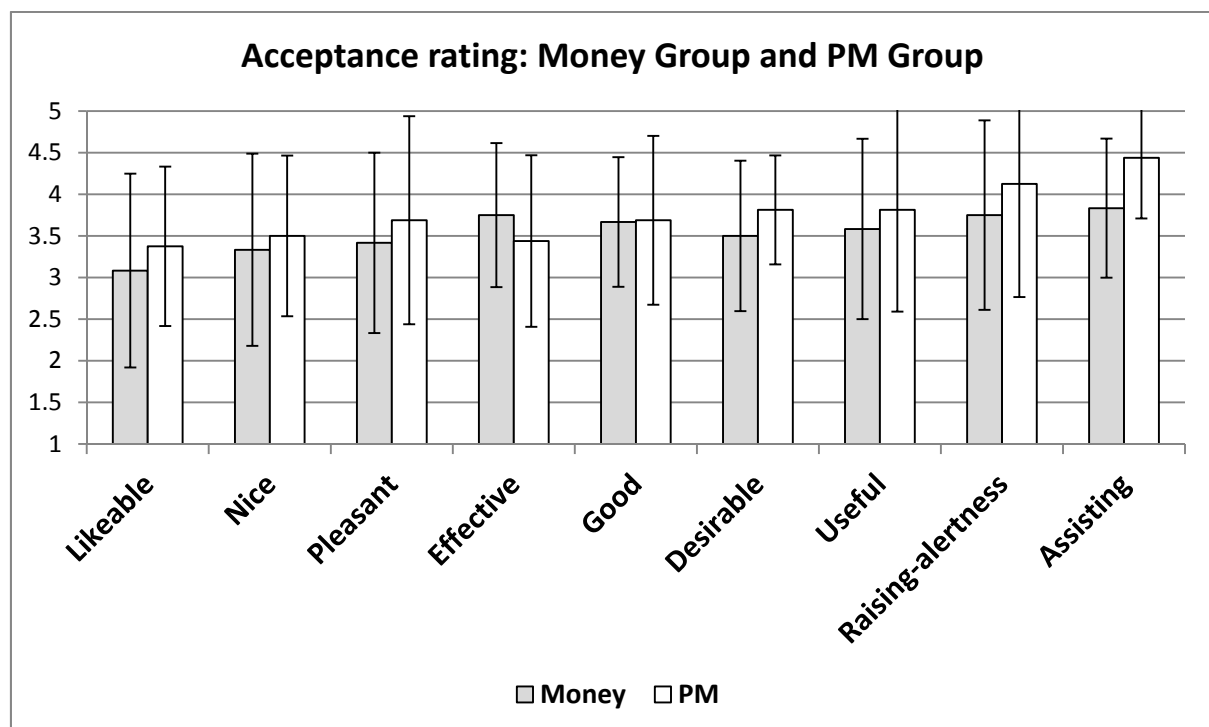


Figure 8.7. The overall acceptance rating (5-point scale, Van Der Laan), with \pm SD as error bars

In the post-test interview, most participants ($N=26$) indicated that the White-Black-Red colors accompanying the Too Slow – Appropriate – Too Fast advices were useful,

alerting (do not have to pay special attention to it), and detectable (cannot be missed). One participant indicated a problem with the red color, because it looked too alarming. Another participant said that he did not need the Too Slow – Appropriate – Too Fast indicator, because the number indicating the advised speed was clear enough.

The auditory distance-keeping advice received mixed comments. More than half ($N=15$) of the participants indicated that the distance cues were clear and good for informing about the distance to the preceding vehicle (including 2 participants who indicated the too far cue was not needed). Some participants ($N=3$) expressed that the distance cues can be improved either by redesigning the auditory information or by having it redundantly accompanied with visual information. Some participants ($N=2$) said that they did not need a distance cue because they could already see it themselves, and one participant said that he did not need a distance cue because distance control should be taken care of by cruise control (e.g. ACC).

8.5.3. Attitude toward Cooperative Driving

Based on the post-test interview results, the convenience of ACC and the benefits of monetary rewards are strong reasons behind participants' willingness to follow platoons of cooperative vehicles. Participants' qualitative answers about ACC and monetary benefits were categorized into Yes, Maybe, and No attitudes.

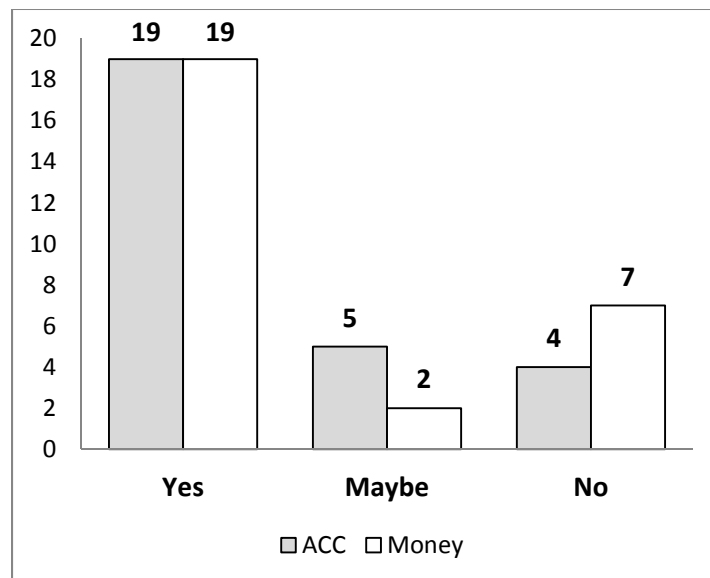


Figure 8.8. ACC and monetary benefits as preferred by participants to influence them to follow cooperative driving

In Figure 8.8, the gray bars show 19 'Yes', indicating the number of participants who were willing to use ACC for cooperative driving, and 4 'No', indicating the participants who considered ACC not trustable. The 5 'Maybe' indicate the participants who liked it but were not sure whether ACC would reduce their

alertness in driving. The white bars show 19 'Yes', indicating the number of participants who were willing to receive monetary benefits while following cooperative driving, and 7 'No', indicating the participants who considered that monetary benefits would not influence them to join platoons of cooperative vehicles. The 2 'Maybe' indicates the participants who were not sure about monetary benefits. Overall, the majority is in favor of both ACC and monetary benefits. Wilcoxon signed rank test does not show a difference between attitude toward ACC and attitude toward monetary benefits, suggesting that both ACC and monetary benefits are equally important to be investigated again for future applications of cooperative driving.

Another reason for participating in cooperative driving is the usefulness of persuasive messages. Messages relating to Time, Sustainability, Safety, Relax were considered useful while following a platoon of cooperative vehicles, because they were considered meaningful when applied in an appropriate context. Time was considered the most useful one. Only Fun messages were not understood by participants. Many participants emphasized that clear and strong messages are very helpful. These participants expressed more inclination to follow the ducks if a message was really urgent, such as a message about an accident ahead. Congestion information was also considered very useful. Some participants ($N=3$) indicated that they did not need persuasive messages (only speed advice needed) as long as the context was appropriate.

Contexts play an important role in influencing participants' general attitude toward cooperative driving, as indicated by the interview results. Participants would participate in cooperative driving when they are tired and want to relax or depending on the mood, when they are not in a hurry or on job-related trips, when the advised speeds are not too low (80 km/h is generally the limit), if everybody else is doing it, and when the behavior of the ducks is appropriate (whether it is safe to follow them). During the experiment, it was observed that participants had problems with the glitches from the simulator showing sudden braking behavior of the ducks (thus considered unsafe). Less frequently mentioned reasons for following cooperative driving were when the road is busy, when driving long distance, during the rain, and if obliged by the government. Some participants mentioned that their behavior in the game was different from their behavior that they would have in real life traffic.

The results of PDV-Q after the experiment were compared to the results of the same questionnaire administered at participants' signup. Using Pearson's correlation, each pair of PDV-Q scores before and after were well correlated ($r > 0.6$), except for Safety ($r=.365$, $p=.056$). The well correlated scores are Sustain ($r=.721$, $p<.001$), Fun ($r=.695$, $p<.001$), Relax ($r=.632$, $p<.001$), and Time ($r=.660$, $p<.001$). For each item (see Appendix

E.1) in Safety, the pre-test and post-test score were compared using Spearman's Rho correlation. Q3 and Q20 had no correlations. Q10 had a mild correlation ($r=.509$, $p=.006$). Similarly Q13 had a mild correlation ($r=.566$, $p=.002$). These findings indicate that overall the reasons for self-evaluated general behavior did not change throughout the experiment, except for Safety, as evident from the moderate or no correlation. Participants' attitude toward speed limits (Q3), electronic traffic signs (Q10), comfort as reasons for distance (Q13), and avoiding accidents as reasons for speed control (Q20) changed during the course of the experiment (see Table E.3 in Appendix E.1 for details).

8.6. Experiment Results – Objective Measurements

8.6.1. Data Processing

As indicated in the hypothesis formulation, the persuasion profile can be measured subjectively (PDV-Q scores) and also determined objectively (behavioral response). The cooperative driving behavior is represented by two indicators: 1) driving behind a platoon of vehicles; 2) adapting speed in order to join a platoon. Therefore, the behavioral response consists of the participants' lane preference and the participants' speed response.

In the case of this experiment scenario, driving behind a platoon of vehicles was indicated by a preference for driving in the right lane upon receiving a Slow Down advice. The right lane preference was measured in two ways: 1) the right lane choice each time an advice is received; 2) the duration of staying on the right lane while receiving an advice. Figure 8.9a shows 'Succeeds' to illustrate the right lane decisions and 'Fails' to illustrate the left lane decisions. In the figure, T_{DRIVING} is a continuous time measurement throughout the driving period (from $T_{\text{DRIVING}} = 0$ to $T_{\text{DRIVING}} = n$, where n is the length of the driving period i.e. the game level).

For each participant, the right lane choice was measured by counting successful cases during the observation period. For example, the period of receiving an advice is between T_{OBSERVE1} in Figure 8.9a and T_{OBSERVE2} in Figure 8.9b. Because of the possibility of changing lane several times during the course of receiving an advice, only the final decision was recorded in order to determine a participant's lane choice for each advice. In Figure 8.9a, the blue car made a left lane choice (yellow path) so $C_{\text{BLUE}} = 0$, and the red car made a right lane choice (green path) so $C_{\text{RED}} = 1$. Before T_{OBSERVE2} , the blue car made a right lane choice (green path) so $C_{\text{BLUE}} = 1$, and the red car made a left lane choice (yellow path) so $C_{\text{RED}} = 0$. For the blue car then we had the right lane choice = successful (1) and for the red car we had the right lane choice = failed (0), based on their final decisions while receiving the advice. For each car, the number of successful cases was then divided by the total number of received advice in order to get a percentage of the right lane choice throughout the driving period.

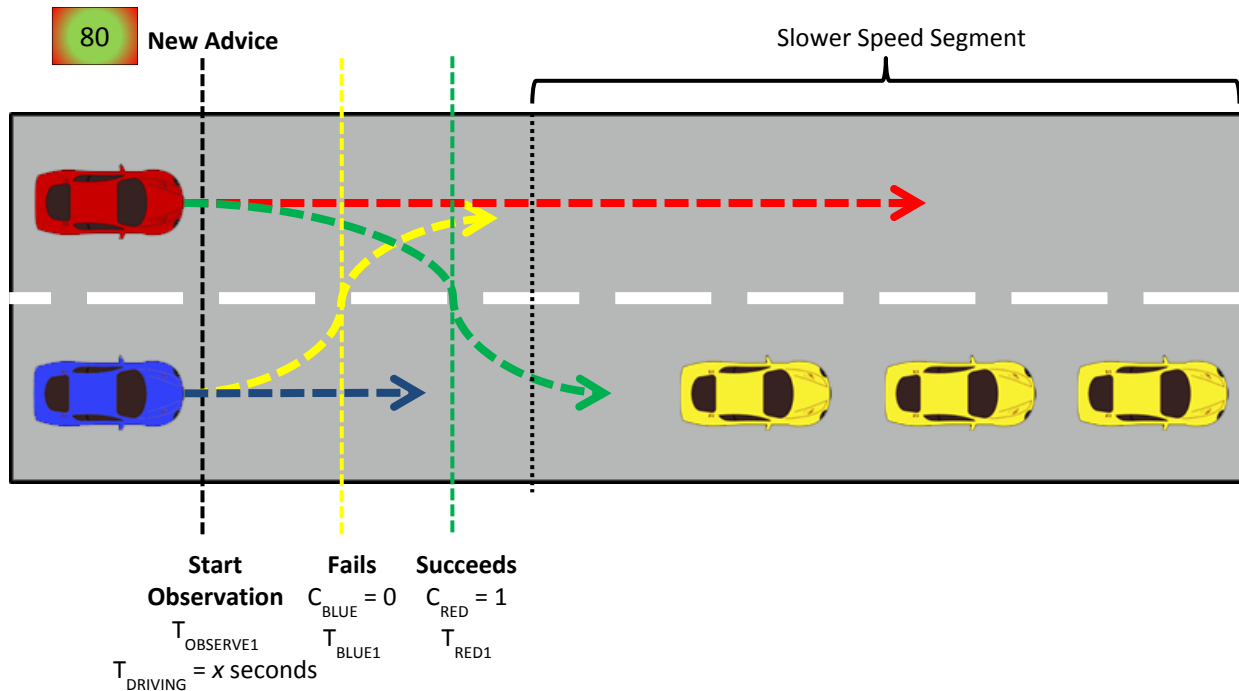


Figure 8.9a. Successful cases: the red car (left lane) taking the green path and the blue car (right lane) taking the blue path. Failing cases: the red car taking the red path and the blue car taking the yellow path.

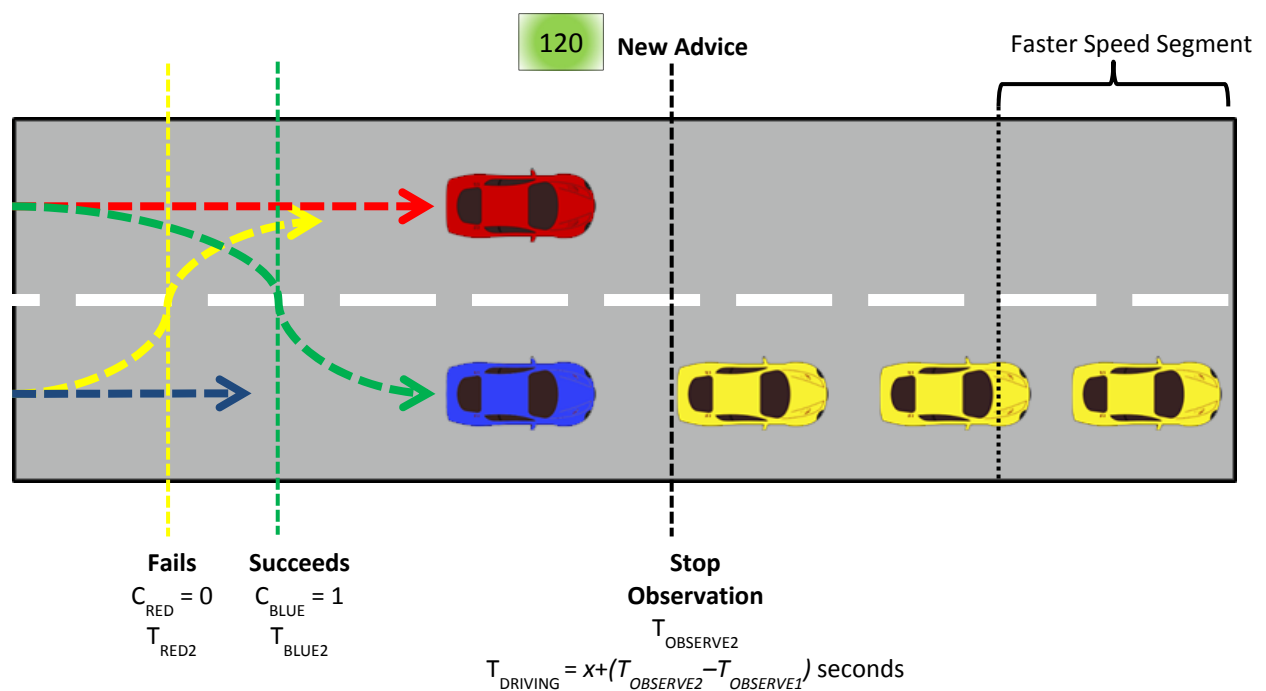


Figure 8.9b. Successful cases: the blue car (right lane) taking the blue path and the blue car taking the green path. Failing cases: the red car (left lane) taking the red path and the red car taking the yellow path.

For each participant, the duration of staying on the right lane was measured by calculating the ratio of driving in the right lane to driving in both lanes while

receiving an advice. We measured the duration of driving in the right lane as well as the whole duration of receiving the advice (irrespective of lane choice). Again take the example of the red car making a right lane choice (green path) at T_{RED1} and the blue car making a left lane choice (yellow path) at T_{BLUE1} as in Figure 8.9a. Therefore, the duration of driving in the right lane for the red car is $(T_{RED2} - T_{RED1})$ seconds. For the blue car, the duration of driving in the right lane is $(T_{BLUE1} - T_{OBSERVE1}) + (T_{OBSERVE2} - T_{BLUE2})$ seconds. For each car, this duration value is added to the duration of staying in the right lane for all other advices. The total duration of receiving advice $(T_{OBSERVE2} - T_{OBSERVE1})$ was also added to that of all other advices. The total duration of staying in the right lane was then divided by the total duration of receiving all advices, resulting in a percentage value for the whole driving period.

In the case of this experiment scenario, adapting speed in order to join a platoon was indicated by slowing down upon entering a road segment with a lower speed limit. In order to calculate the speed response of a participant toward an advice, for each advice the speed was sampled every 50ms by the driving simulator producing a speed curve. For each speed curve, a line of best fit was constructed using linear regression. The line represents a slope of speed change (km/h vs. second), where -1 means a speed decrease of 1 km/h per second and +1 means a speed increase of 1 km/h per second. Figure 8.10 illustrates a participant's different speed responses toward different advices, represented by the curves and the slope values.

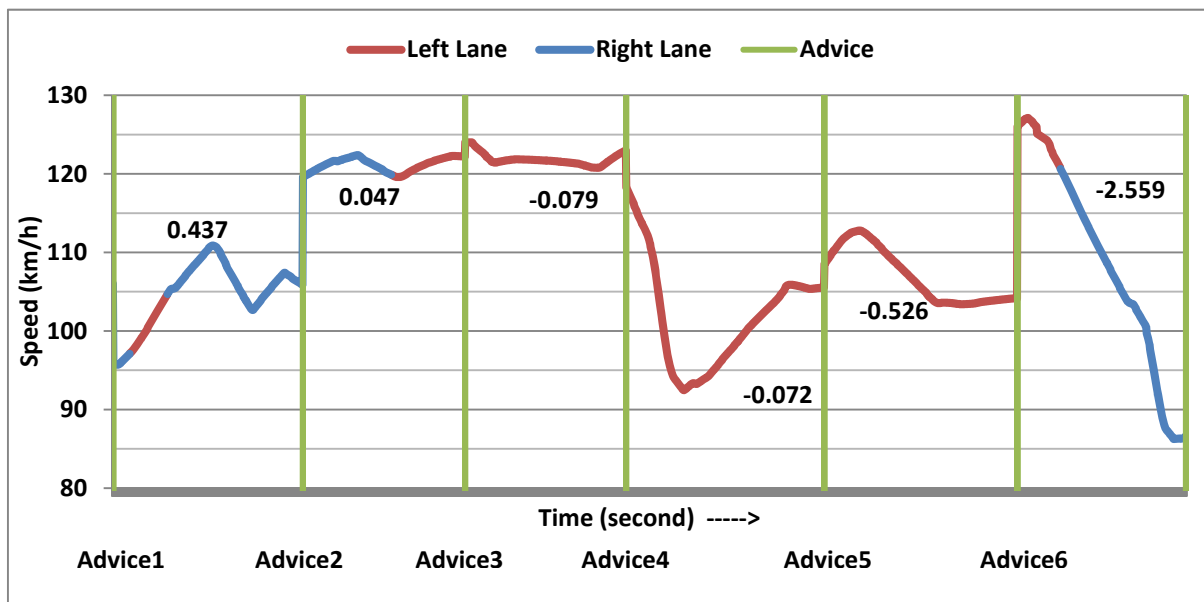


Figure 8.10. A participant driving through 6 advices, where at each advice his speed is sampled independent of lane choice. The participant changes lanes between left and right. For each advice, a response slope is calculated. A negative response slope as after Advice6 indicates compliance toward the 80km/h speed advice.

For both lane preference and speed response, a measurement started as soon as an advice was displayed to the participant. In Phases 2-3-4, a new advice was displayed

99 meters before a road segment with a new speed limit (as illustrated by Figure 8.9a-b). The measurement stopped as soon as the driver complied (speed difference less than 5 km/h) or as soon as the road segment ended. Therefore, the duration of the measurement depended on the driver's behavior. The number of samples taken into the calculation of the speed response slope also depended individually on the participant's speed and response to the advice. On average it ranged from 38.12 to 217.8 samples (indicating a speed response with duration of 1.91s to 10.89s respectively).

Since there was no advice in Phase 1, the baseline measurement regarded a window of 3.2s time gap to the preceding car. The slowing down behavior was measured within this window while the preceding car (part of a platoon) was reducing its speed.

In Phase 2, participants received two levels of speed advice: low (70-80 km/h) and high (110-120 km/h). Each participant received the same set of speed advices (Appendix E.2), but the number of Slow Down advices received by each participant depended individually on the participant's speed. For example, a driver complied with an advice and then exceeded the speed limit again, thus he received a new advice of the same speed limit. Only the responses to the low speed advices were used to represent Phase 2 responses, because only the low advices were accompanied by persuasive messages in Phases 3-4.

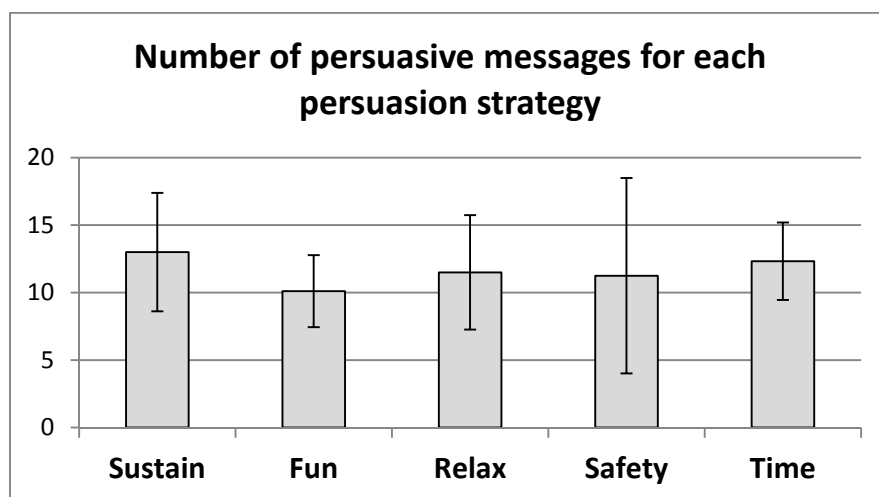


Figure 8.11. The average number of persuasive messages received by participants throughout Phase 3 (Levels 5 and 6), with \pm SD as error bars

In Phase 3, the number of received persuasive messages differed per participant, because it depended on the relative speed of the participant to the target speed at a given advice. Upon each 80km/h speed advice, a participant could choose to follow or ignore. If the participant was driving in a low speed, following the speed advice required less time to comply with and caused the display of the advice to stop. If the

participant chose to ignore the advice, he/she experienced a longer period of receiving the persuasive message. An overview of the number of persuasive messages received by participants throughout Phase 3 is shown in Figure 8.11.

8.6.2. Comparison between Phases

The average percentage of right lane choice is 35.84% for Phase 1¹⁰, 60.22% for Phase 2, 67.79% for Phase 3, and 67.67% for Phase 4 (as shown in Figure 8.12). Repeated measures analysis showed a significant result ($F_{3,81}=37.711$, $p<.001$). The significant differences were between Phase 1 and Phase 2, between Phase 1 and Phase 3, and between Phase 1 and Phase 4. This indicates that speed advice increased right lane choices. While persuasive messages also increased right lane choices compared to no advice, they did not result in a larger increase compared to speed advice only.

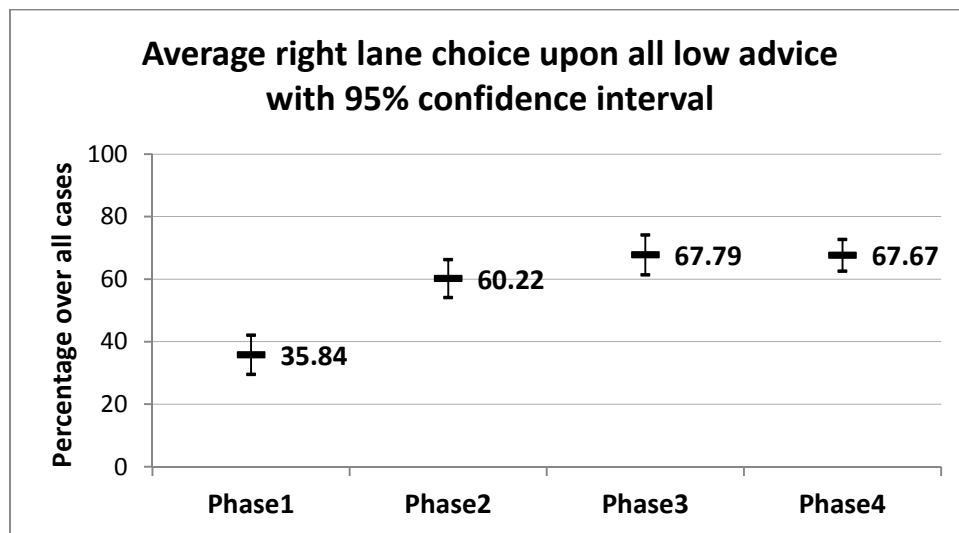


Figure 8.12. Right lane choices averaged from all 28 participants per phase

The average percentage of right lane duration is 48.73% for Phase 1¹¹, 60.53% for Phase 2, 54.76% for Phase 3, and 66.28% for Phase 4 (as shown in Figure 8.13). Repeated measures analysis showed a significant result ($F_{3,81}=9.819$, $p<.001$). The significant differences were between Phase 1 and Phase 2, between Phase 1 and Phase 4, and between Phase 3 and Phase 4. This indicates that speed advice resulted in a longer duration of staying in the right lane. Persuasive messages did not cause longer duration of staying in the right lane compared to speed advice only.

¹⁰ Phase 1 had different traffic settings between levels, inducing different average of right lane choice (28.45% for Level 1, 50.09% for Level 2). Level 2 is not significantly different from Phase 2 (Levels 3 & 4), but we cannot use Level 2 only for representing Phase 1. This is due to the very large individual differences between participants (Note: $(28.45\% + 50.09\%)/2 = 39.27\%$, but the weighted average for Phase 1 = 35.84%).

¹¹ 39.38% for Level 1, 67.32% for Level 2

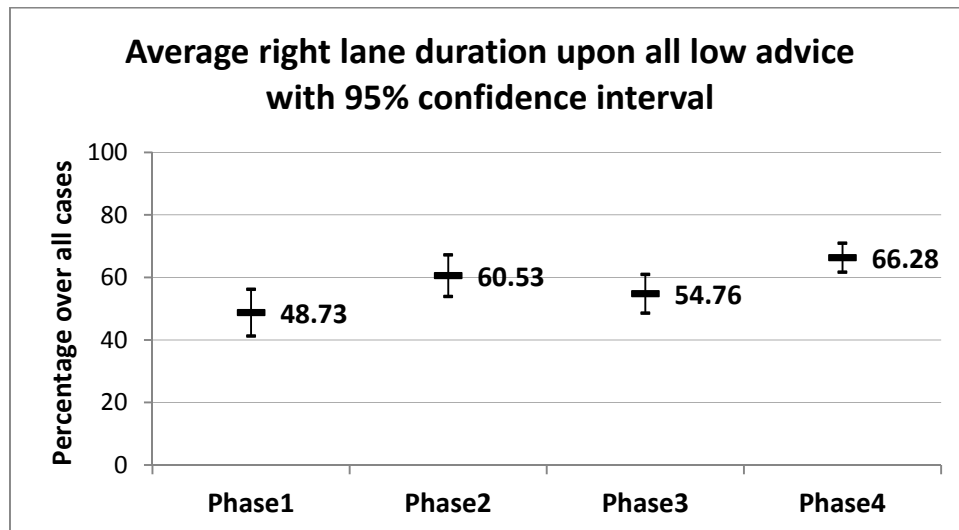


Figure 8.13. Right lane duration averaged from all 28 participants per phase

The average speed response slope is -0.58 for Phase 1, -1.294 for Phase 2, -1.266 for Phase 3, and -1.084 for Phase 4 (as shown in Figure 8.14). Repeated measures analysis showed a significant result ($F_{3,81}=6.489$, $p=.001$). The significant differences were between Phase 1 and Phase 2 as well as between Phase 1 and Phase 3. This indicates that speed advice increased speed compliance. While persuasive messages also increased speed compliance, they did not result in extra compliance compared to speed advice only.

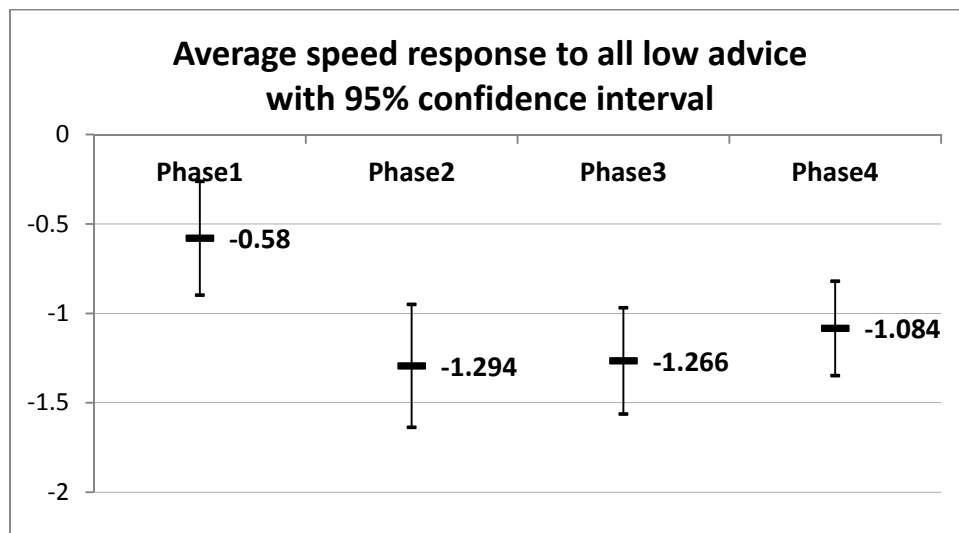


Figure 8.14. Speed response slopes averaged from all 28 participants per phase

Based on the results in Figures 8.15, 8.16, and 8.17, we show that participants changed their behavior due to speed advice only. **Therefore, hypothesis H1 “Speed advice influences drivers’ speeding behavior and increases the likelihood that they join a platoon, compared to a baseline situation without speed advice” is supported.**

8.6.3. PDV-Q Based Profiles

In the previous sub-section, Phase 3 and Phase 4 responses included responses to all persuasive messages, both those which were compatible with the PDV-Q based profiles and those which were not. In this sub-section, we discuss only the results for responses to persuasive messages that were compatible with the PDV-Q profiles.

The first step was to find whether there were any correlations between the behavioral responses toward persuasive messages representing each persuasion strategy and the PDV-Q scores corresponding to the persuasion strategy. In all Phase 1, Phase 2, and Phase 3, correlations were not significant between right lane choice upon Sustainability messages and Sustainability score, right lane duration while receiving Sustainability messages and Sustainability score, speed response slope toward Sustainability messages and Sustainability score; and the same held for the other persuasion strategies (Fun, Relax, Safety, Time). This suggests that the PDV-Q scores of participants did not predict the behavioral responses while driving with persuasive messages.

The next step was to focus on the behavioral responses toward persuasive messages representing only the strongest persuasion strategy based on each participant's PDV-Q based profile. These persuasive messages were considered compatible with the participant's PDV-Q based profile. As mentioned in Section 8.4.1, based on PDV-Q we found 20 participants with a Safety profile, 5 participants with a Time profile, 2 participants with a Fun profile, and 1 participant with a Relax profile. From this point we label these corresponding persuasive messages PDV-Q based messages.

The right lane choice while following PDV-Q based messages in Phase 3 was then calculated; and the results are shown in Figure 8.15. A repeated measures analysis on the right lane choice between Phase 1, Phase 2, and Phase 3 (PDV-Q) was conducted. The effect of phase was significant ($F_{2,54}=25.337$, $p<.001$). The significant differences were between Phase 1 and Phase 2 as well as between Phase 1 and Phase 3. This indicates that PDV-Q based messages in Phase 3 increased right lane choices, but they did not result in more increase compared to speed advice only.

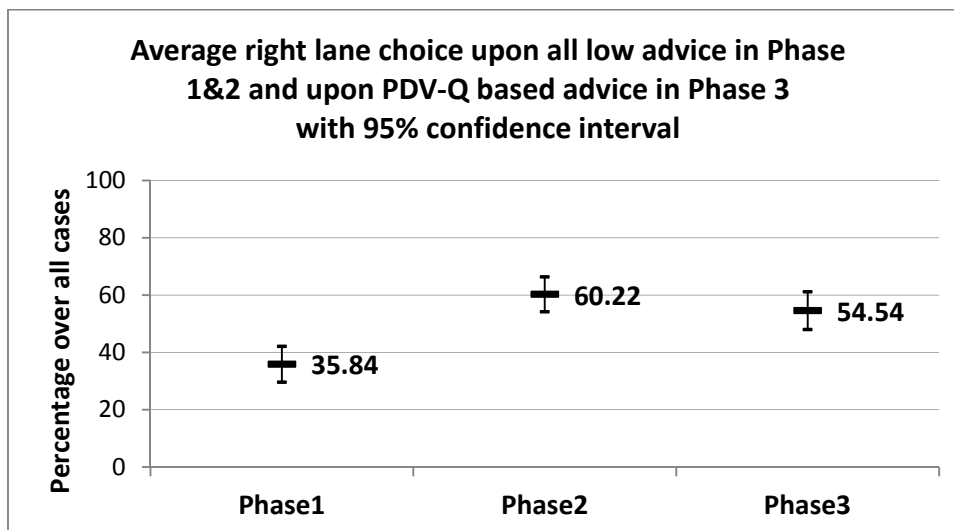


Figure 8.15. Right lane choices averaged from all 28 participants, for PDV-Q based profiles

Results for duration of staying on the right lane are shown in Figure 8.16. A repeated measures analysis between Phase 1, Phase 2, and Phase 3 (PDV-Q) was conducted. The effect of phase was significant ($F_{1.835,49.536}=6.104$, $p=.005$), but only the difference between Phase 1 and Phase 2 was significant. This indicates that PDV-Q based messages in Phase 3 did not cause longer duration of staying in the right lane.

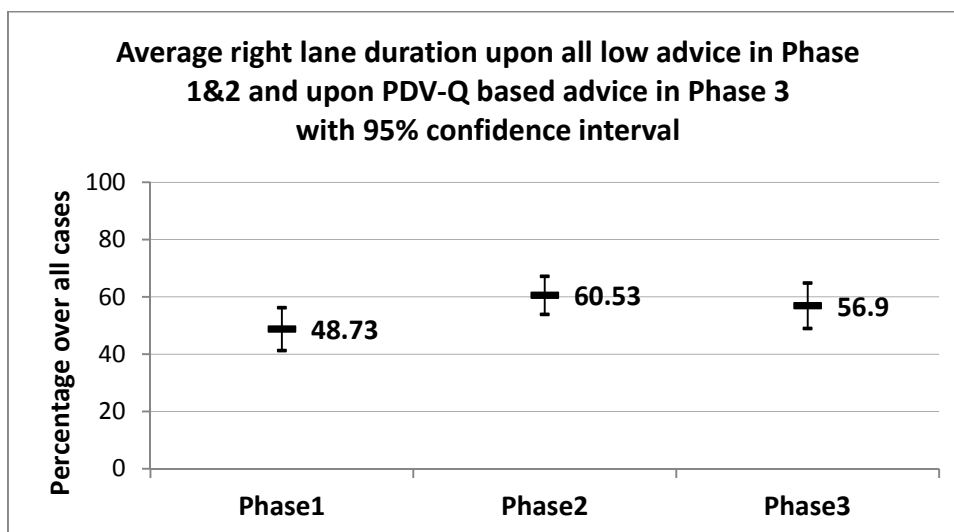


Figure 8.16. Right lane duration averaged from all 28 participants, for PDV-Q based profiles

Results for speed response slopes are shown in Figure 8.17. A repeated measures analysis between Phase 1, Phase 2, and Phase 3 (PDV-Q) was conducted. The effect of phase was significant ($F_{2,54}=5.080$, $p=.01$), but only the difference between Phase 1 and Phase 2 was significant. This indicates that PDV-Q based messages in Phase 3 did not cause better speed compliance.

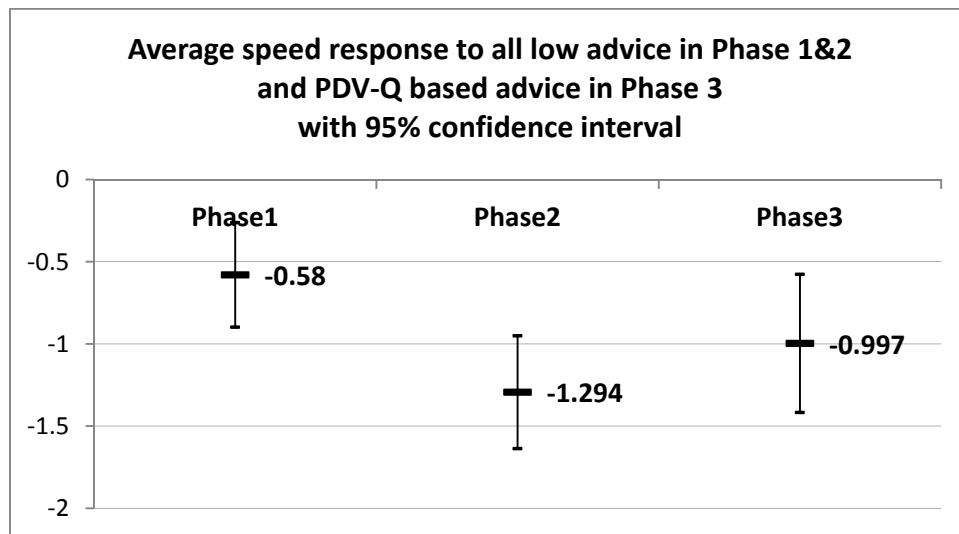


Figure 8.17. Speed response slopes averaged from all 28 participants, for PDV-Q based profiles

Based on the results in Figures 8.18, 8.19, and 8.20, we show that participants changed their behavior due to speed advice, and that persuasive messages that are compatible with the participants' persuasion profile as derived from the PDV-Q scores did not strengthen their compliance with the speed advice. **Therefore, hypothesis H2a "The driver's persuasion profile as mentioned in H2 can be determined on the basis of his PDV-Q scores" is rejected**, where H2 is "Persuasive messages that are compatible with a driver's persuasion profile strengthen the drivers' compliance with speed advice, compared to a speed advice only condition."

8.6.4. Behavior Based Profiles

In order to find the behavior based persuasion profiles, participants' responses to each persuasion strategy in Phase 3 and Phase 4 were measured. The strongest responses (based on right lane choice, right lane duration, and speed response slopes) were used to determine the objective persuasion profile of a participant. In order to determine the validity of these behavior based profiles, we compared the three types of strongest response: right lane choice, right lane duration, and steepest speed response slope. If this is a valid method for determining persuasion profiles, then the three results for each participant should show the same persuasion profile represented by the most effective persuasive messages.

Table 8.5. The behavioral response of 28 participants in Phase 3, based on right lane choice, right lane duration, and speed response slope. Consistent outcomes for different measures are printed in bold.

Participants	PDV-Q	Measure		
		Lane Choice	Lane Duration	Speed Response
user01	safety	safety	sustain	fun
user02	safety	time	time	fun
user03	safety	sustain	sustain	sustain
user04	safety	fun	fun	time
user05	safety	sustain	safety	relax
user06	safety	fun/relax/sustain/time	fun/relax/time	sustain
user07	safety	sustain/time	safety	safety
user08	time	relax	safety	relax
user09	safety	relax	time	sustain
user10	fun	relax	time	time
user11	safety	relax	fun	relax
user12	time	fun	safety	relax
user13	safety	relax	fun	sustain
user14	safety	fun	fun	safety
user15	safety	relax	relax	safety
user16	fun	fun/relax	time	fun
user17	time	sustain	time	sustain
user18	relax	safety/sustain/time	fun/sustain	fun
user19	safety	relax	safety	relax
user20	time	time	fun	sustain
user21	safety	sustain	fun	sustain
user22	safety	relax	time	relax
user23	time	relax	safety	relax
user24	safety	relax	time	sustain
user25	safety	time	fun	relax
user26	safety	time	safety	time
user27	safety	time	relax	relax
user28	safety	time	time	relax

For Phase 3 (as shown in Table 8.5), all participants were included in the analysis. For Phase 4 (as shown in Table 8.6), the analysis could only be performed on the PM group, because the Money group only received monetary messages (these messages were not given in Phase 3). For each participant, the profile based on the right lane preference was determined by finding the type of persuasive messages that elicited the highest percentage of right lane choice. The same was done for right lane duration. The profile based on the speed response was determined by finding the type of persuasive messages that elicited the steepest average speed response slope. Calculation of lane choice and lane duration showed that a few participants always decided for the right lane or spent all time on the right lane after receiving different types of persuasive messages. For these participants, not a single type of persuasive

message was more effective, and therefore no persuasion profile could be determined (see columns 'Lane Choice' and 'Lane Duration' as in Tables 8.5 and 8.6).

Table 8.6. The behavioral response of 16 participants (PM group) in Phase 4, based on right lane choice, right lane duration, and speed response slope. Consistent outcomes for different measures are printed in bold.

Participants	PDV-Q	Measure		
		Lane Choice	Lane Duration	Speed Response
user02	safety	relax/safety/time	time	safety
user04	safety	time	relax	relax
user05	safety	safety/sustain	sustain	safety
user06	safety	sustain	safety	safety
user07	safety	safety	relax	relax
user10	fun	safety/time	safety	safety
user14	safety	safety/sustain	safety	time
user15	safety	relax/time	safety	safety
user16	fun	safety	relax	safety
user17	time	safety	safety	time
user19	safety	safety	time	relax
user21	safety	relax/safety	safety	time
user22	safety	relax	relax	time
user24	safety	relax/safety	safety	relax
user26	safety	relax	relax	relax
user27	safety	safety	time	relax

In Table 8.5, it is shown (in bold) that only 3 out of 28 participants behaved consistently according to the three measurements in Phase 3. In Table 8.6, it is shown (in bold) that only 4 out of 16 participants behaved consistently according to the three measurements in Phase 4.

In the experiment (see Figure 8.11), each participant received several messages for each persuasive strategy. Therefore, each participant had several chances to respond to each strategy. Speed response slopes per participant were investigated in order to find out whether the multiple messages of the same persuasion strategy were always responded with similar strength in speed response. 28 ANOVA analyses on the speed response slopes with persuasion strategies as the independent variables shows that for only 2 out of 28 participants the effect of strategy was significant.

In order to find consistency between PDV-Q based profiles, behavior-based profiles in Phase 3, and behavior-based profiles in Phase 4, a similar comparison was performed. The results did not show consistency of participants' behavioral response to persuasive messages between Phase 3 and Phase 4. The side-by-side comparison between Phase 3 and Phase 4 is detailed in Appendix E.4.

Overall, constructing a profile for each participant only based on the strongest behavioral response to messages representing a persuasion strategy did not lead to a valid persuasion profile. The strongest response for each participant was not always distinctly stronger than the responses toward other messages by the same participant. It might have been coincidental (see details in Appendix E.3).

Based on the results in Tables 8.5 and 8.6, we show that participants changed their behavior due to speed advice, and that participants' behavioral response to persuasive messages did not result in valid persuasion profiles. **Therefore, hypothesis H2b "The driver's persuasion profile as mentioned in H2 can be determined on the basis of the driver's compliance with speed advice, compared to a speed advice only condition" is rejected,** where H2 is "Persuasive messages that are compatible with a driver's persuasion profile strengthen the drivers' compliance with speed advice, compared to a speed advice only condition."

8.6.5. Monetary Persuasive Messages

In order to evaluate the effect of monetary rewards on cooperative driving behavior, in Phase 4 the Money group received Money messages. Since in Sections 8.6.3 and 8.6.4 it was shown that PDV-Q based and behavior based persuasive messages did not strengthen the likelihood of cooperative driving behavior, the response to messages presenting monetary rewards in Phase 4 were compared to the behavior in the other phases. For Phase 3, the average of all persuasive messages was used for comparison. The reasoning is as follows. There were three sources of behavior data for Phase 3: 1) behavioral response to PDV-Q based messages; 2) strongest behavioral response to messages representing a particular persuasion strategy; 3) behavioral response to the average of all persuasive messages. The behavioral response to PDV-Q based messages was not the strongest one compared to behavioral response to messages not representing their PDV-Q profiles. And according to the previous section, the average of strongest behavior toward a particular persuasive message in Phase 3 was not consistent in Phase 4 (Tables 8.5, 8.6, 8.7). Therefore, the first and second sources of behavior data were not used in the comparison.

A repeated measures analysis on the right lane choice showed a significant result ($F_{3,33}=15.095$, $p<.001$), as in Figure 8.18. Post-hoc comparison showed that lane choice in Phase 1 was different from all the others, but there was no difference between Phase 4 (Money messages) and Phase 3 (non-monetary messages) or Phase 2 (advice without persuasive messages). This indicates that Money messages in Phase 4 increased right lane choices, but they did not result in more increase compared to speed advice and non-monetary messages. Based on lane choice, there was no effect of monetary messages in comparison to speed advice and non-monetary messages.

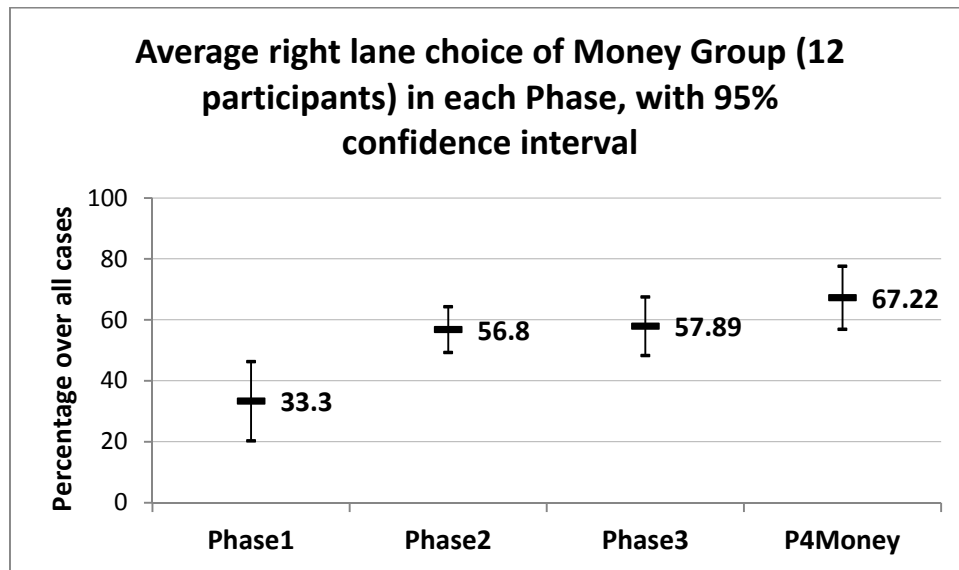


Figure 8.18. Right lane choice between phases, averaged from 12 people in Money group

A similar analysis was conducted for duration of staying in the right lane. Results are shown in Figure 8.19. The repeated measures analysis showed a significant result ($F_{3,33}=9.456$, $p<.001$). Post-hoc comparison showed that there was no significant difference between Phase 1 and Phase 3, between Phase 2 and Phase 3, and between Phase 2 and Phase 4. There was a significant difference between Phase 1 and Phase 2, between Phase 1 and Phase 4, and between Phase 3 and Phase 4. This indicates that driving with non-monetary messages (Phase 3) did not increase right lane preference compared to driving without advice (Phase 1) and driving with advice only (Phase 2). Driving with monetary messages (Phase 4) did not increase right lane preference compared to driving with advice only (Phase 2), but it did increase right lane preference compared to driving without advice (Phase 1) and driving with non-monetary messages (Phase 3).

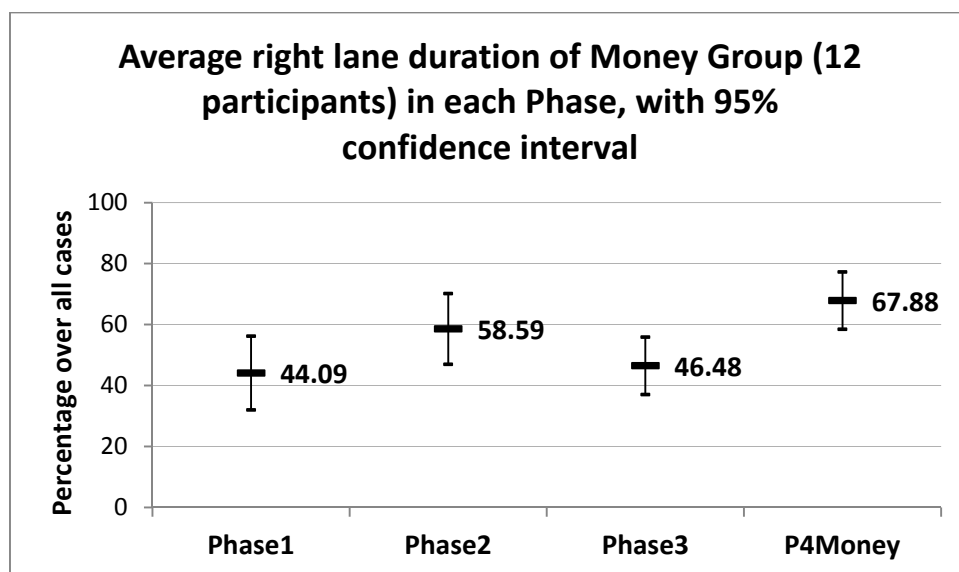


Figure 8.19. Right lane duration between phases, averaged from 12 people in Money group

A similar analysis was conducted on the speed response slopes. Results are shown in Figure 8.20. The repeated measures analysis showed no significant results. For the 12 participants in the Money group, speed response slopes between phases were not different. The confidence intervals for each Phase are quite wide, indicating a wide difference in the speed response behavior of participants who expressed a dislike for persuasive messages.

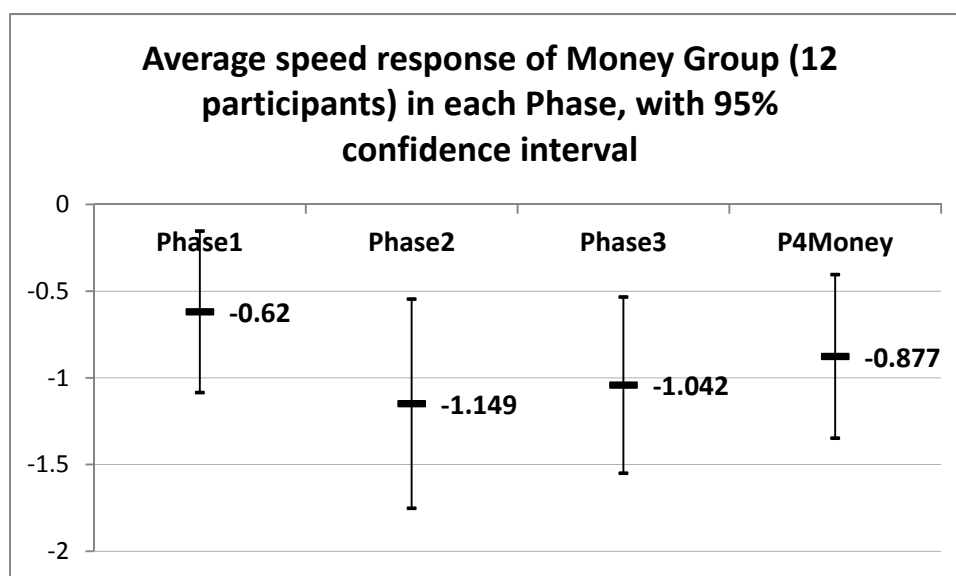


Figure 8.20. Speed response slopes between phases, averaged from 12 people in Money group

Based on the results in Figures 8.21, 8.22, and 8.23, we show that participants changed their behavior due to speed advice only. **Therefore, hypothesis H3 “Monetary rewards strengthen drivers’ compliance with speed advice, compared to a speed advice only condition” is rejected.** In addition, based on the right lane duration monetary messages may be more effective than non-monetary persuasive messages in keeping drivers compliant with the advice.

8.7. Conclusion and Discussion

The driving game experiment has addressed the following hypotheses.

- H1: Speed advice influences drivers' speeding behavior and increases the likelihood that they join a platoon, compared to a baseline situation without speed advice.
- H2: Persuasive messages that are compatible with a driver's persuasion profile strengthen the drivers' compliance with speed advice, compared to a speed advice only condition.
- H2a: The driver's persuasion profile as mentioned in H2 can be determined on the basis of the driver's PDV-Q scores.
- H2b: The driver's persuasion profile as mentioned in H2 can be determined on the basis of the driver's behavioral response to persuasive messages.
- H3: Monetary rewards strengthen drivers' compliance with speed advice, compared to a speed advice only condition.

From the experiment results, the following conclusions may be drawn. In the first place, all behavioral responses (based on lane preference and speed response) indicate participants' compliance with speed advice compared to their baseline behavior. Therefore, hypothesis H1 is supported.

In the second place, the profile obtained from PDV-Q scores did not predict participants' responses to persuasive messages as observed in Phase 3. Therefore, hypothesis H2a is rejected.

In the third place, it was found that the strongest behavioral response to messages representing a particular persuasion strategy could be determined, both based on lane preference and speed response. However, the strongest behavioral response did not consistently and reliably determine the persuasion profile. Therefore, hypothesis H2b is rejected.

Summarizing H2a and H2b, although overall behavioral responses indicated participants' compliance with persuasive messages, this compliance was not higher than the one with speed advice only. Therefore, hypothesis H2 is rejected.

In the fourth place, it was found that the group who received monetary messages complied with speed advice compared to their baseline behavior. This group was also compliant with monetary messages. However, the compliance with monetary messages was not stronger than the compliance with speed advice only. Therewith, hypothesis H3 is rejected.

Overall, this experiment did not show that persuasive messages can increase people's compliance with a speed advice in order to participate in cooperative

driving. Although participants evaluated their behavior using PDV-Q, the self-assessment of their behavior did not predict the behavioral response to persuasive messages while driving. Furthermore, while participants explicitly indicated liking for persuasive messages, the preferred messages also did not match the persuasive messages responded by them while driving. Moreover, we could not determine any pattern in the behavioral responses of participants, so that we could not determine the persuasion profiles of participants. In the following paragraph, we will discuss that there was a profound effect on the measurement process as induced by the experimental setup: 1) using serious game setting; 2) using a driving simulator.

The aim of using a serious game approach in this experiment was to prevent participation bias and hide the goal of the experiment. The results of this experiment suggest that the game may have been successful in preventing participation bias, i.e. the compliance with the advice was actually different from the compliance in the other conditions. At the same time, the game may have rerouted participants' goals, i.e. instead of complying with the advice they tried to win the game. Thus, the game was successful in introducing gaming behavior, but may have caused inappropriate data acquisition leading to less relevant data. The fact that roughly a third of the participants used the exit/emergency lane in order to win the game suggests that the chosen setup may have elicited artificial, game-like behavior, which is not representative of normal traffic behavior. This artificial, game-like behavior may also have induced motivational forces conflicting with the motivation that could be influenced by the persuasive messages. Especially in Phase 4, participants of the PM group responded to persuasive messages with less steep speed response slopes, indicating less slowing down. The steeper response slopes (more slowing down) in Phase 3 compared to Phase 4 may be due to a novelty effect in Phase 3. Alternatively, participants may have driven faster in Phase 4 in order to win the game, as it was the last chance to do so.

The limitations of the driving simulator also may have reduced the consistency of the experiment condition across participants. One observable limitation is the sudden brakes of the platoons that happened randomly, although it mostly happened when a participant approached a platoon too quickly. As mentioned in the post-interview, this issue gave an impression toward participants that a platoon of cooperative driving may follow dynamic speed limits too rigidly, inducing unsafe behavior. In addition, participants' speed response to Safety messages was on average quite weak compared to their responses to other persuasive messages in Phase 3. Also, participants' attitude toward driving slower to improve safety and attitude toward complying with dynamic speed limits to benefit the traffic flow were slightly more negative after the experiment (see the end of Section 8.5.3). All of these suggest participants' mixed attitude toward safety issues in cooperative driving because of their experience during the experiment.

The use of persuasion in an automotive context was demonstrated by this experiment, but the selected persuasion route was not proven effective. The experiment employed a central route to persuasion i.e. using personally relevant driving values. This method allows drivers to consciously decide to comply with the advice based on their personally relevant values. The experiment result shows that there was a difference between persuasion profiles obtained through PDV-Q and persuasion profiles obtained through driving behavior. The majority of participants scored high in Safety based on PDV-Q response, but many of them did not respond as strong toward Safety persuasive messages (Tables 8.5 and 8.6). Although the Safety scores of participants were not reliable (low Cronbach's Alpha / narrow distribution of scores), participants who scored high in other dimensions of PDV-Q also showed the same inconsistency. The difference between their highest PDV-Q scores and their strongest response to the corresponding persuasive messages indicated that participants might have reacted to messages that they did not consciously intend to react to, or vice versa. When they did respond the strongest to messages representing a particular persuasion strategy, the strength of the response was not distinct compared to the responses to other messages, indicating coincidental responses (Appendix E.3). This may be caused by the very short timespan that participants had between receiving a persuasive message and applying the advised speed. A possible explanation is that participants had to react to the persuasive message and at the same time had to adjust their vehicle according to the traffic situation. This explanation is supported by the literature (Petty & Cacioppo, 1986) that distraction may influence the central processing of a persuasive message.

Reviewing the theory used for this experiment, the goal of CSA is to provide motivation, ability, and opportunity supports for drivers to participate in cooperative driving. The study in this chapter evaluated CSA as a motivation support by using personal driving values. Whether CSA can be used as a reliable behavior change support system could not be confirmed by this study. This may be due to the short period of the experiment and the artifacts created through the experimental setup. The design of the experiment as a game created different contexts for the same experiment condition (see Appendix E.2, Table E.4), inducing effects on the measurement process as explained above.

Regarding motivation support, the results of this experiment provide insights for improving the persuasive messages used in CSA. Firstly, the visualization of the messages may need to be improved. Although participants did not comment on the clarity of the visual representation, it can be improved for better recognition. Secondly, the persuasion profiles used in the experiment may have not been the proper ones for the purpose of increasing the compliance with the advice. The persuasion profiles need to contain more than just personal driving values, e.g. preference for messages about traffic events. The extra messages, as obtained from

the qualitative comments of participants in this experiment, matched the qualitative comments of participants in the focus groups and the previous driving simulator test (see Chapter 2), and were also confirmed by previous studies (CVIS Project, 2007; van Driel & van Arem, 2005). Examples of such messages are “Accident ahead” and “Traffic blocked ahead”.

Although participants subjectively indicated liking for monetary benefits, the hypothesis about monetary messages was rejected. During the experiment, the monetary benefits that participants could gain may have been set too little in comparison to the monetary losses that participants could incur while playing the game. In the experiment we used 0.2 Euro as rewards and 0.1 Euro as penalty, denoting that a reward is only twice as much as a penalty. Participants could earn rewards anytime they complied with the system, but it would get easily reduced to half as soon as they received a traffic fine. A relevant field experiment (Hultkrantz & Lindberg, 2011) used fixed rewards instead of variable rewards (participants could not gain extra rewards based on their behavior), but the maximum penalty was set to only 30% of the low rewards and 15% of the high rewards. Comparing between the groups who received low rewards and the group who received high rewards, there was no difference in the participants’ behavior. The penalty was the only one that changed the behavior of participants, regardless of receiving high or low rewards. Comparing our results and theirs suggests that people are more likely to change their behavior by avoiding losing a given reward than by working toward extra rewards (earning “reverse fine”).

Participants also subjectively indicated a liking for the ACC system. Apart from monetary benefits, the convenience of ACC was considered by participants as persuading them to participate in cooperative driving. As ACC provides ability support, it can be concluded that the work in this chapter also addressed the ability support for cooperative driving.

The opportunity support by CSA could not be completely observed in the work in this chapter. Due to the random behavior of the simulated traffic provided by the driving simulator, the advice given by the CSA prototype did not always match the situation in the scenario. The scenarios used in the experiment may have not been representative of real life situation. This insufficient opportunity support led to driver’s confusion when deciding on what action to take upon receiving information from the CSA prototype. If the driving simulator can be improved in a way that the car can have the V2X¹² communication system functionality, the CSA prototype would give a better opportunity support.

¹² Vehicle to Vehicle, Vehicle to Infrastructure

As a final remark, this experiment yielded a list of considerations for conducting future experiments on persuasive technology for supporting behavior change in the driving context:

- The effects of persuasive messages on the participants' behavior may have been too subtle to measure, suggesting the need of a more sensitive measure.
- Stable behavioral patterns of participants have not been established properly, suggesting the need of a longer period of data collection.
- The persuasion strategy used in the experiment may have not been appropriate for the driving context.
- The scenarios used in the experiment may have not been representative, suggesting the need for a field experiment in order to evaluate behavior change in a real life situation.

9

Conclusion and Discussion

9.1. Contributions of this Thesis

This thesis consists of two parts. The first part presents studies on the user interface for a portable in-vehicle system. The second part presents studies about a persuasion concept for increasing driver's compliance with cooperative driving. The studies were aimed at the development of Cooperative Speed Assistance (CSA) with reference to the Connect & Drive Project (2008).

The main goal of this thesis was to answer the following research questions:

1. How should user interfaces inform drivers about recommended speed-related behavior in order to be alerting but not distracting? (Interaction Design)
 - What is the format of an effective speed advice (What, When, and How of speed advice)?
 - What is the relevant content for the speed advice: speed or acceleration?
 - What is the optimal combination of visual and auditory modalities for the user interface of CSA?
2. How do we maximize the compliance of drivers with the system, such that drivers adopt a new behavior in order to participate in cooperative driving? (Persuasion Design)
 - How do we identify the most appropriate persuasion strategy in order to change driver's behavior toward cooperative driving behavior?
 - How do we evaluate CSA as a behavior change support system, using the most appropriate persuasion strategy?

9.1.1. Advisory System for Cooperative Driving

In the beginning of the project, we decided to use recommended speed as the information to be presented to drivers. In order to elicit user requirements, focus group discussions were conducted, indicating that users preferred advisory systems (CSA) over automated systems (C-ACC) and that they expected to receive information about the reasons behind and the consequences of following a speed advice. The requirements gave rise to two prototypes: a Guidance prototype (advice only) and an Explanation prototype (providing reasons and consequences of the advice). These concepts were evaluated in a driving simulator. Test participants found the Explanation prototype better for recognizing the urgency of advice because of the extra information.

In order to compare speed advice and acceleration advice, a driving simulator experiment was conducted for two different conditions: light traffic (small speed fluctuation) and heavy traffic (large speed fluctuation), while using the acceleration interface or the speed interface (2x2 experiment design). The results indicated that one group of participants preferred speed advice because of the freedom in the

implementation of the advice, and another group of participants preferred acceleration advice because of the precision in distance keeping. Using acceleration advice caused less speed fluctuation in heavy traffic and more stable distance keeping, but it caused more frequent throttle pedal changes. It was found that participants drove with a shorter time gap while using their preferred interface, leading to a better traffic throughput.

This thesis presented an advisory system for cooperative driving based on a speed advice concept with three states: Too Slow, Appropriate, Too Fast. Based on qualitative comments from experiment participants, this concept is more useful than the existing dynamic speed limit information systems on the highway, in terms of the relevance of the advice. The dynamic speed limit information on the electronic message boards above highways display one-size-fits-all information that may not apply to all drivers. In the case of compliant drivers (who try to comply with speed limits), the information acts as a confirmation. In the case of non-compliant drivers (who disregard speed limits), the information acts as a repetition and tends to get ignored.

In older versions of portable navigation devices (PNDs), a warning about traffic speed limit is displayed to drivers each time a speed camera is detected. These PNDs display the warning irrespective of the vehicle's speed, alerting drivers unnecessarily each time a speed camera is detected. In newer versions of PNDs, the warnings are displayed in relation to the speed of the vehicle, as provided by the setting for speed cameras "Warn me only if I'm exceeding the speed limit". This is comparable to CSA, but CSA does not only warn. In addition, CSA provides continuous advice as long as the advice is valid. Therefore, drivers can become aware of their speed at all times, without having to wonder whether the system is going to give new speed limits or not.

Existing PNDs may have a good coverage for detecting traffic jams ahead, but they do not yet communicate with highway infrastructure regarding dynamic speed limits for regulating traffic flow. They provide information about delays to travel time, but they do not link the time delay with a speed advice for each vehicle. Having CSA is an added value to a navigation system. Using CSA, the information about the time delay can be linked to the Too Slow, Appropriate, and Too Fast states of the vehicle's speed.

9.1.2. Portable In-Vehicle System for Cooperative Driving

In a portable in-vehicle system, only visual and auditory interfaces are available due to the practical limitation of a nomadic system and constraints from vehicle manufacturers. In order to reduce the visual burden while driving, we tested an auditory interface displaying the same information as conveyed by the visual interface (redundancy information). In the exploratory study, a concept for visual and auditory interfaces was developed. The visual interface was designed for peripheral vision, using white-black-red color changes for Too Slow, Appropriate, Too Fast respectively. The auditory interface was designed for displaying a series of tones conveying two meanings: Speed Up and Slow Down. Experiment participants considered that the auditory interface did not add any value to the speed advice information. They judged the color changes in the peripheral display as more action triggering than the auditory signals. Therefore, we proposed an improvement to the auditory interface by having urgency information encoded in the sound signals and testing it without any visual interface.

Using simple tones instead of other forms of auditory interface (speech, auditory icons, earcons), we evaluated two concepts: Looping (signals displayed as long as the target speed is not reached) and Toggle (signals displayed only once and then followed by an 'OK' signal as soon as the target speed is reached). Two prototypes were developed, a 2-pulse design (two pulses in a burst) and a 3-pulse design (three pulses in a burst) and tested with a driving simulator test. The majority of test participants preferred the Toggle concept because it was judged as less stressful and the OK signal was considered useful. The majority of test participants preferred the 2-pulse prototype over the 3-pulse prototype, because it was considered as less annoying, simpler, and easier to understand. Both concepts and prototypes were rated equally in terms of mental effort, i.e. all of them were rated low ("some effort"). They were also rated as low in annoyance, and moderately helpful in recognizing urgency. There was no difference in terms of driver's speed compliance with the advice while driving with any of the concepts and prototypes.

Based on the user requirements, we proposed a user interface design for the final prototype of CSA that can be combined with a PND system. The decision for the visual interface is to have the navigation information displayed on the center of the screen while keeping the colored display elements on the perimeter of the screen. The color changes allow drivers to use peripheral vision in receiving the speed advice. The usefulness of color changes in the peripheral vision was confirmed again by users in the studies in Chapters 4 and 8. The study in Chapter 4 also demonstrated the usefulness of distance advice. In addition, the auditory interface was found to be advising users without the presence of a visual interface (Chapter 3). Therefore, we decided to use the auditory interface (simple tones in a reduced application of Looping concept) for distance advice. The study in Chapter 8 demonstrated that this

auditory interface was not annoying, and more than half of experiment participants found it useful.

Although a driver's visual attention is burdened by the driving task, we learned that the use of the visual modality still has an advantage over the auditory modality, in terms of annoyance and distraction. Using visual information, the system can inform the target speed continuously without having to induce annoyance to the driver. Although it has not been extensively explored, we proposed the use of a peripheral visual display in order to enable drivers to use their peripheral vision. In a recent study, it was found that the use of peripheral vision while driving keeps the driver's central vision on the road for blind spot warning and reduces reaction time significantly for speed warning and distance warning (Langlois, 2013). The study compared driving with only icons behind the steering wheel and driving with both icons and a peripheral visual display. Using only icons, the average glance duration on the icons for speed and distance warnings was 0.7s to 1.45s. Using a peripheral display, the average glance duration on the icons was only 0.11s to 0.48s. Therefore, the use of a peripheral visual display was found to be much less distracting than the use of icons behind the steering wheel. The design of CSA using a peripheral visual interface meets the requirements of giving the speed advice continuously without distracting and annoying the drivers, but still alerting them.

Apart from meeting the requirements of minimal annoyance and distraction, we learned that the user interface design of CSA also meets the requirements of portability. By using only visual and auditory interfaces, the system can be easily retrofitted to any vehicle. It can also be easily deployed in smart phone applications, with present day wireless technology that has already made possible the V2I (Vehicle to Infrastructure) communication. At present there is no robust technology for V2V (Vehicle to Vehicle) communication via portable devices, apart from GNSS (Global Navigation Satellite System), which is known as GPS (Global Positioning System) of USA and EGNOS (European Geostationary Navigation Overlay Service) of Europe. This technology is not accurate enough to measure distance between vehicles. A robust technology for communication between high speed vehicles in an ad hoc manner was demonstrated in the Connect & Drive project (Ploeg et al., 2011). This technology should be available in the near future (Broadcom, 2013), which can then be made available in portable devices.

This thesis has described the steps toward developing a multimodal interface for a portable in-vehicle system for supporting drivers in cooperative driving. The multimodal interface consists of visual information and auditory information. The visual information is used for presenting the speed advice as long as the advice applies, and the auditory information is used for presenting the distance advice only when it is critical.

9.1.3. Tailored Persuasion Strategy in the Driving Context

CSA is a persuasive technology or behavior change support system. Using CSA enables drivers to change their behavior in order to engage in cooperative driving. For developing CSA as a persuasive technology, certain types of feedback i.e. monetary rewards, immediate feedback and positive feedback were selected. While the monetary rewards are targeted at extrinsic motivation, we decided to target intrinsic motivation as well. The interaction between intrinsic motivation and other factors can be explained using the Motivation-Ability-Opportunity (MAO) framework (Ölander & Thøgersen, 1995).

In the MAO framework, the Motivation element covers values, personal relevance, and needs, which can be used for identifying individual differences in motivation. Because of these individual differences, we need different persuasion strategies. The MAO Framework supports tailored persuasion strategy, as proposed by Graml, Looock, Baeriswyl, & Staake (2011) for distinguishing different user groups and their preferred way of communication.

This thesis provides an example of such a process of distinguishing different user groups by identifying the difference in their behavior in traffic. The links between personally relevant factors and the driver's motivation were established by a literature study on driver's attitude and behavior in speed related situations. These personally relevant factors are safety, being responsible to others, emotional state like having fun and feeling relaxed, eco driving issues, time saving, and money issues.

We proposed a way to identify differences in personal values among drivers using a questionnaire that reports behavior and its underlying reasons, called the Personal Driving Values Questionnaire (PDV-Q). The questionnaire items were generated through brainstorming and inferred from the literature on driver attitude and behavior discussed in Chapter 6. After validating with 250 drivers, 6 factors (Sustainability, Relax, Fun, Safety, Time, Fines) were extracted as personal values in driving. Driver profiles were analyzed and used to construct persuasion profiles that correspond to persuasion strategies. The persuasion profile of a driver is characterized by his/her strongest personal driving value, and determines which persuasion strategy the driver is most susceptible to.

We learned that the use of PDV-Q has implications for selecting driving experiment participants with specific profiles. For example, after the analysis of the profiles of the 250 drivers, most of them displayed a Safety or Fines profile. It was found that older drivers are more likely to have a Safety profile and less likely to have a Fines profile.

The work in this thesis has identified personal differences among drivers in terms of the reasons behind their habitual behavior. The statements generated for the PDV-Q can be generalized for understanding the users of other traffic applications.

9.1.4. Persuasion Design for Cooperative Driving

The goal of the persuasion design is to increase the driver's compliance with CSA, so that the driver will engage in cooperative driving. In order to test whether persuasive technology can be used for influencing drivers, the notion of a persuasion profile based on PDV-Q was used. The personal driving values identified by PDV-Q target both intrinsic (non-monetary: Sustainability, Relax, Fun, Safety, Time) and extrinsic (monetary: Fines) motivation. Based on these sources of intrinsic and extrinsic motivation, a set of persuasive messages was designed as visual icons. The icons were displayed with Slow Down advice for low target speeds.

The persuasion design was tested using a serious game experiment, because the use of driving simulator as a test facility is not suitable for a long-term behavior study. The game included real monetary rewards in order to influence people's attitude toward monetary messages. The overall results indicated that experiment participants were already compliant with the speed advice, and persuasive messages (both monetary and non-monetary) did not increase their compliance. At the end of the experiment, participants experienced Adaptive Cruise Control (ACC) as a bonus level. The majority of participants expressed a positive attitude toward ACC and the monetary benefits, indicating that ACC and monetary benefits would influence them to join platoons of cooperative vehicles. As shown by the qualitative results, the context played an important role in influencing participants' attitude toward cooperative driving. Examples of contexts that favor their participation in cooperative driving: when not in a hurry, when the recommended speed is not too low, and if everybody else is doing it.

The work in this thesis has shown that drivers differ in their behavior while complying with speed advice. Although the differences could not be confirmed through persistent behavior, the results provided insights about the influence of different types of messages on drivers' behavior. The results of Chapter 2 also indicated the advantage of using extra messages on top of speed advice only. Participants in the exploratory study considered the extra information as motivating them to respond to advice from CSA. Learning from the qualitative results of Chapter 8, the content of the messages should be relevant to the traffic condition, suggesting that using different types of persuasive messages may be applicable for other driving assistance systems.

Some recommendations about the content of persuasive messages were addressed in the focus group discussion and by the qualitative results of the driving simulator test in Chapter 2, which are in line with the qualitative results of the driving simulator experiment in Chapter 8. They are also in line with previous studies (CVIS Project, 2007; van Driel & van Arem, 2005). This leads to a need of gathering these results into one single guideline that can be used for providing extra information that is persuasive as well as suited for detecting the urgency of a speed advice.

9.1.5. Practical Implications

Insights for practical implications of a portable CSA system were generated based on the studies in Chapters 2, 3, 4, and 8. The ideal CSA has a user profile setting, which can be derived from subjective data (preferences) and objective data (behavior) of the user.

The user's preferences consist of advice only vs. extra information, types of advice (speed vs. acceleration), and user interface modality of information presentation. The following examples are user's preferences in plain words. 'I prefer advice only when commuting' (set the destination of commuting); 'I prefer advice with extra information when driving long distance' (set the number for distance in kilometers); 'I prefer acceleration advice in a traffic jam' (an option between speed and acceleration advice); 'I prefer visual only when my radio is on and auditory only when driving alone' (options in relation to the vehicle's entertainment system and the vehicle's seat sensors). Based on these preferences, a user profile is built.

The system learns a user's behavior by recording which messages are responded by users with a compliance with the system. In order to learn a user's behavior, the system recommends the user to use extra information as the default setting in the beginning of the usage. After an extended period of use the system will give an advice only when it is relevant to the user. A relevant advice is the one that increases the user's compliance in terms of information content and in terms of the speeds that the user finds acceptable. However, as in other automated intelligent systems, the fact that the system learns the user's behavior may not appeal to all users. In this case, users can also select to receive only information that is relevant, such as safety-related, time-related, sustainability-related, or obstacles information such as road construction and accident ahead.

9.2. Reflections

9.2.1. *Accommodating Differences among Drivers*

The way in which the results from the questionnaire were used for accommodating differences among drivers in cooperative driving can be improved. The work in this thesis did not use an existing validated persuasion theory such as the one proposed by Cialdini (2007), because many of these strategies translate poorly to traffic situations. A study based on Cialdini's theory (Kaptein, Markopoulos, de Ruyter, & Aarts, 2009) reported consistency between self-reported susceptibility to a particular persuasion strategy and the actual compliance with the corresponding strategy. Its authors reconfirmed the consistency in a follow-up study (Kaptein et al., 2012). Constructing persuasion profiles from an existing validated persuasion theory may lead to a higher consistency between the questionnaire response and the behavior, compared to constructing persuasion profiles from a newly established framework such as the driving values as extracted by the PDV-Q.

Such a validated persuasion theory for the driving context does not exist. Although the statements used as the PDV-Q items were for the larger part already addressed in previous attitude and behavior studies (as summarized in Section 6.4.2), there are no specific studies integrating all of these attitudinal and behavioral items into a taxonomy of personal values for the driving context, which could be used as a basis for choosing persuasion strategies. The work in this thesis can contribute elements that might support the development of a persuasion theory, because there is no evidence that our definition of persuasion profile through the PDV-Q is flawed. The results of PDV-Q in Chapter 8 (28 participants) resemble the results of PDV-Q in Chapter 7 (250 participants), which show two groups of correlated scores: Relax-Safety-Sustain and Fun-Time. The PDV-Q results before and after the experiment (4 weeks apart) in Chapter 8 showed a good test-retest reliability, except for the Safety score. As discussed at the end of Chapter 8, we argue that this is not a problem of the questionnaire items, but it is more likely caused by the change in the participant's attitude during the serious game experiment.

It is also important to conduct more validation tests for PDV-Q, possibly by including the original 49 items in the test. By including the 49 items, the questionnaire may yield different items constructing the factors, leading to extraction of different factors. For example, the Driving Behavior Questionnaire (DBQ) has been tested more than ten times (Ozkan, Lajunen, & Summala, 2006) resulting in a variation of factors (2 and 4 compared to the original 3) as well as confirming its stability across cultures and low test-retest factor stability. High test-retest reliability means that testing a questionnaire on the same population over a period of time shows the same factors. To use PDV-Q for generating persuasion strategies, we need to ensure high test-retest factor stability, because attitude, behavior and habit are not

short lived (although changeable). Test-retest reliability on attitude should be good within two weeks, although a very strong attitude may stay over decades (Spector, 1992). By conducting more iteration on validation tests, PDV-Q will be more robust as a means of self-reporting personal driving values that are related to persuasion strategies.

9.2.2. Research Methods and Tools

9.2.2.1. Measuring Speed Compliance

As of the writing of this thesis, there is very little related work on measuring speed-compliance behavior in cooperative driving. Most studies on cooperative driving were conducted on automated systems. The studies on advisory systems reported distance between vehicles as a measure of traffic stability and average speed as a measure of traffic throughput (van den Broek et al., 2010; van den Broek, Netten, & Lieverse, 2011), driver's ability in carrying out headway advice (Risto & Martens, 2011) and external influence on driver's tendency in adjusting their headway (Gouy, Diels, Reed, Stevens, & Burnett, 2012).

The most closely related studies on speed compliance are the ones conducted on advisory systems for Intelligent Speed Adaptation (ISA), which used different methods. For example, Lahrmann, Agerholm, Tradisauskas, Berthelsen, & Harms (2011) used the proportion of distance driven above the speed (PDA) as a measure of the effect of Intelligent Speed Adaptation (ISA). PDA was measured using the distance driven above the speed limit set by ISA and compared with the same measure while driving without ISA. This measure was considered as more sensitive than the mean free flow speed measure.

In Chapter 2, there was no analysis of driver behavior. In Chapter 3, the analysis was performed by measuring the rate of speed change in the first 5 seconds after a speed advice, because it was aimed at measuring compliance toward speed advice. In Chapter 4, the analysis was conducted for mean speed and variance in speed, because it was aimed at measuring stability of traffic. In Chapter 8, the analysis was conducted for speed response slope in order to measure compliance toward speed advice. This method sampled the speed changes toward the compliance of an advice and measured its linear regression in order to get a slope value. Considering the different measurements for the different contexts, steps were taken toward a sensitive measure of speed compliance behavior. We were able to derive from the objective data that CSA assisted drivers in complying with platoon's speed compared to driving without CSA. However, there is a need for further study and standardization.

9.2.2.2. Simulator Test Validity

Blaauw (1982) reported absolute and relative behavioral validity for longitudinal vehicle control and relative behavioral validity for lateral vehicle control using a fixed-base simulator. Lee, Cameron, & Lee (2003) reported that over two-thirds of the variability of the on-road driving performance can be explained by driving simulator performance. On the other hand, Godley, Triggs, & Fildes (2002) reported that participants drove faster in the instrumented car than in a moving-base simulator, and Bella (2008) reported that participants drove faster in the simulator than on the road due to the difference in risk perception. In this thesis, a simulator test (Chapter 4) was conducted with the same speed profiles used in a field test. The results of these two tests are not directly comparable in terms of absolute validity (the actual speed chosen by test participants). However, in terms of relative validity (slower or faster) the result can be translated into real world behavior.

Another limitation of using driving simulator is the simulator sickness of experiment participants, which is related to physical validity. However, during the four driving tests conducted for this thesis, none of the participants reported simulator sickness symptoms.

As learned from the work in this thesis, a driving simulator test has limitations when used for studying behavior change. Studying behavior change requires a long term measurement, which is not possible with a single session experiment. Designing the experiment for allowing extended use of the simulator is very challenging. Also, it is difficult to induce real world goals. Using the simulator as a gaming system can be considered, but the incremental difficulty levels in a game may introduce too many different experiment conditions, which can interfere with the acquisition of adequate behavior data.

9.2.2.3. Time Headway vs. Time Gap

In the literature, there are different measures for distance between vehicles: time headway and time gap. Studies in cooperative driving conducted on both automated and advisory systems used time headway (Naus & Vugts, 2010; Ploeg et al., 2011; van den Broek et al., 2010). These studies referred to time gap settings used in previous studies, but they used the term 'time headway' for specifying distance settings in their studies. El Ghouti, Serrarens, Van Sambeek, & Ploeg (2009) explicitly stated that a distance gap in meters is representative of time headway in seconds, which implies that time gap is the same as time headway. Green (2012) pointed out the same usage inconsistency between gap and headway in many scientific papers.

Time headway is the time between the front of the following vehicle and the front of the preceding vehicle. Time-gap is the time between the front of the following vehicle and the rear of the preceding vehicle. For engineering studies, the difference between

time headway and time gap is negligible, because the length of the car does not influence the behavior of the control system (Ploeg et al., 2011). Therefore, the results of Chapter 4 can be used by engineering studies. However, these inconsistencies make it very difficult to compare results of human factors studies. We suggest that engineers working on cooperative driving technology standardize their terms in order not to confuse human factors specialists while assessing the technology with human drivers. Both engineers and human factors specialists are advised to refer to a standard document in progress (Green, 2013) in the publication of their results.

9.3. Suggestions for Future Research

9.3.1. Gradual Speed Advice

The current concept of CSA provides advice in a discrete manner. Providing advice in a gradual manner (from discreet to alerting) may prepare drivers in anticipating a new target speed of varying urgency levels. It would support the ability of drivers in monitoring their behavior from time to time.

Studies have reported the success of gradual haptic warning (Lee, Hoffman, & Hayes, 2004) and gradual auditory warning (Fagerlönner, Lindberg, & Sirkka, 2012). Lee et al. (2004) reported that graded alerts were more trusted than single stage alerts. It is interesting to investigate gradual alerts through visual information.

9.3.2. Peripheral Visual Interface

Designing an interface for peripheral vision may extend the modality of driver-vehicle interfaces. In existing PNDs, the screen design forces drivers to use central vision while driving. For example, dynamic speed limit information is displayed with a speed value on a white background with a red border as used in road traffic signs instead of any relative or gradual indication (e.g. faster, slower, or approaching speed limit). This design takes a very small part of the screen space due to the rest of the space needed for the main application. A speed advice does not necessarily need to be very accurate in speed target, because drivers can already be influenced just by detecting the appearance and disappearance of colors, as demonstrated in this thesis.

Comparing the effectiveness of focal (for central vision) visual interfaces as in existing systems and ambient (for peripheral vision) visual interfaces as in this thesis may confirm the advantage of ambient visual interfaces. It is useful to conduct investigations using eye tracking studies for comparing central and peripheral visual attention in specific applications (Langlois, 2013) such as speed advice. Such eye tracking studies will also contribute to determining the spatial area of peripheral vision with respect to the driver's eyes, which will inspire vehicle manufacturers to improve the spatial location of current in-vehicle visual displays.

9.3.3. Multimodal Interface

Studies conducted by Ho & Spence (2008) and literature reviews conducted by Cao & Theune (2010) present the advantages of tactile modality for warning type of information. They reported that drivers reacted within shorter times toward tactile warning compared to visual only or auditory only warning. Within a multimodal interface, auditory and tactile did not cause significant difference in reaction times, visual and auditory did not cause significant difference in reaction times, but visual and tactile caused significant difference (Scott & Gray, 2008). Combination of auditory and tactile also increased reaction times compared to auditory only and tactile only (Ho, Reed, & Spence, 2007).

A tactile interface as provided by vibrotactile feedback (vibration from sound waves) is relatively easy to create, in the same manner as creating simple tones for an auditory interface. It can be deployed on the steering wheel, under/behind the driver's seat, or wearable by the driver. Vehicle manufacturers should allow third party portable systems to extend their interfaces using vibrotactile feedback attached to the interior of the vehicle.

Tactile interfaces have been investigated in studies on navigational information (Boll et al., 2011) and collision warning (Ho, Reed, & Spence, 2007; Scott & Gray, 2008). An investigation of tactile interfaces for speed advice will reveal whether tactile modality has an advantage over other modalities in this context. It will also influence design decision on other systems that need speed advice.

9.3.4. Long-term Field Test

Studies on driver behavior change using field tests may bear resemblance in results compared to driving simulator studies in terms of absolute and relative behavioral validity, as discussed in Section 9.2.2.3. Therefore, it is necessary to conduct a field operational test (FOT) in order to observe driver behavior with better validity. For measuring the behavior change, it is necessary to combine FOT with a naturalistic driving study (NDS). In an NDS, the measurement of behavior is conducted in everyday driving conditions. It leads to a better understanding of driver behavior over a period of time. The combination of FOT and NDS is called naturalistic FOT (FOT-Net, 2010).

Longitudinal studies conducted by Lee, Lim, & Lee (2011) supported a measurement of behavior change; Vlassenroot et al. (2007) supported a measurement of attitude change and acceptance; Hultkrantz & Lindberg (2011) and Lahrman et al. (2012) supported a measurement of incentives effect. Such studies would benefit from another measurement a few months later, in order to find out whether the behavior change persists or not. Thøgersen (2009) reported that after five months, the effect of the influencer (incentives in this case) became weaker, but it was still evident.

A longitudinal study on advisory systems for cooperative driving can be conducted before having V2V communication, as soon as the infrastructure is ready for V2I communication. In the Netherlands, a pilot highway strip for such infrastructure was realized, supported by different parties (a PND company, the ministry, the local government, and an automotive research institute). They conducted a 3-month study to observe the effect of in-car speed advice on driving behavior and traffic flow (Passchier et al., 2013).

9.3.5. CSA as Part of a C-ACC System

Although the motivation of developing CSA is to provide a transition before C-ACC matures, CSA can continue to be used even after C-ACC matures. The Connect & Drive Project (2011) reported that there was a significant difference between driving with C-ACC (lower mental workload) and driving with no assistance, but there was no significant difference in mental workload between driving with CSA and driving with no assistance. Although lower mental workload seems to be the advantage of C-ACC, full automation may cause mental underload and decrease in alertness of the drivers (Young & Stanton, 2002). To keep drivers engaged, CSA may be deployed as an option in a C-ACC system. Moreover, drivers may encounter trust issues in delegating the control to the vehicles (Verberne, Ham, & Midden, 2012).

In this case, more questions arise. Which technology will finally be preferred by people? Will people trust automation or will people prefer to be in control? How do we balance between the good traffic throughput (C-ACC) and the ability to control the vehicle movement (CSA)? How do we balance the trust issue (C-ACC) and the mental workload issue (CSA)? These questions call for further research.

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Appendix A (Chapter 2)

A.1. Focus Group Structure

1. Pre-questions

- Have you ever used portable car devices such as TomTom?
- If yes, what do you think about it?
 - What's good/useful about it
 - What's bad/annoying about it
 - How would you improve it
- Have you ever used a car with cruise control?
- If yes, what do you think about it?
 - What's good/useful about it
 - What's bad/annoying about it
 - How would you improve it

Show a video about ACC from an existing system (Audi's ACC)

- What do you think about it? [10 minutes]
 - What's good/useful about it
 - What's bad/annoying about it
 - How would you improve it
- Would you trust such a system? [5 minutes]

2. Show an animation with explanation about a possible C-ACC/CSA scenario

There's a traffic jam 5 km ahead. The length of the traffic jam would take you 20 minutes to go through it. The traffic jam is pulling off, so that in 5 minutes it will be only 3 minutes length. Therefore, the communication system calculates your speed to arrive there in 5 minutes. It tells your car to slow down to 60 km/h. This way, you will take 5 minutes to the traffic jam location. Your current speed is 120 km/h, which would take you 2.5 minutes to the traffic jam. If your car doesn't slow down, by the time you arrive at the traffic jam, it will still be 10 minutes length. Therefore, C-ACC system would save your time ($3 + 5 = 8$ minutes, instead of $10 + 2.5 = 12.5$ minutes) to reach your destination.

Questions:

- What do you think about it? [10 minutes]
 - What's good/useful about it
 - What's bad/annoying about it
 - How would you improve it
- Would you trust such a system? [5 minutes]
- How would you like to be informed? [10 minutes]
 - What ways/modality do you like to be informed with? (Advised speed or "slow down" advice? Etc)

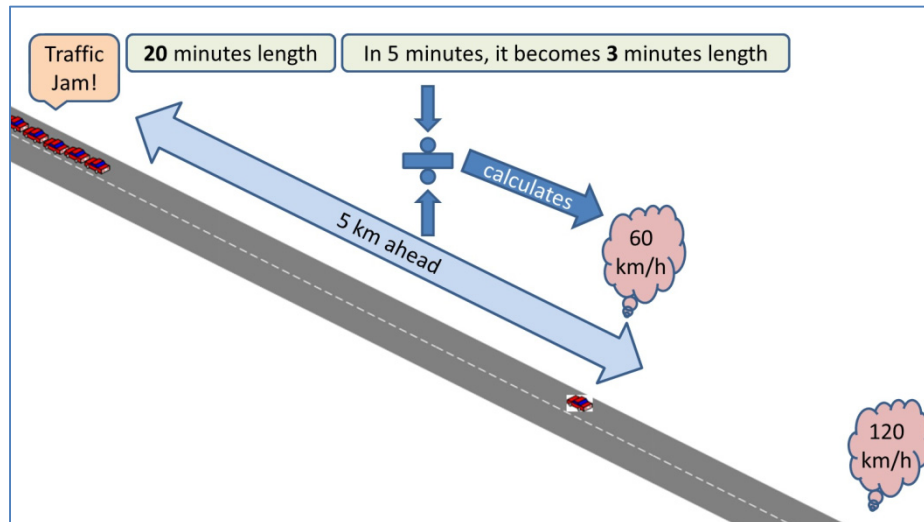


Figure A.1. The animation as shown in the focus group discussions. It shows a car that changes speed from 120 km/h to 60 km/h because of a traffic jam ahead.

3. Show slides about C-ACC and CCC feedback systems

C-ACC:

- A visual cue shows signals (arrow down up to 70km/h).
- An auditory cue shows signals (tone down).

CCC:

- The system tells the driver that he has to slow down before a traffic jam. A visual cue shows signals (arrow down up to 70 km/h).
- An auditory cue shows signals ("Traffic jam. Slow down").
- A haptic pedal gives a pressure upwards (no more acceleration).

What do you think about those systems? [10 minutes]

- Which modality do you prefer?
- How would you trust/react?

Assume that you are driving in a highway, where there is a traffic jam ahead. What kind of information do you want to know? [10 minutes]

- How many kilometers ahead
- The length of the traffic jam
- Others?

A.2. Color Contrast Analysis



Figure A.2. Color Contrast Analysis for the Color Blind, conducted with Vischeck (Dougherty & Wade, 2009 - 2012). The figures above are as visible by color blind people, from left to right: Deuteranope (red-green), Protanope (another form of red-green), Tritanope (blue-yellow), respectively.

A.3. Questionnaire for Driving Test Participants

Questionnaire 1: Prototype Elements

No	Items	Not at all	Somewhat Not	So-so	Somewhat Yes	Definitely
1	The Guidance Prototype is:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
2	The Explanation Prototype is:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
3	The color changes in both prototypes are:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
4	The buttons in Explanation Prototype are:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
5	The icons in Explanation Prototype are:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
6	The "Speed Up" sound in both prototypes is:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					
7	The "Slow Down" sound in both prototypes is:					
	Useful					
	Difficult to understand					
	Important					
	Annoying					

Questionnaire 2: Urgency and Taking Action

No	Items	False	Somewhat False	Undecided	Somewhat True	True
1	Guidance Prototype					
	I can sense low urgency situations while using the device					
	I can sense medium urgency situations while using the device					
	I can sense high urgency situations while using the device					
	I want to take action upon the color changes					
	I want to take action upon hearing the sounds					
2	Explanation Prototype					
	I can sense low urgency situations while using the device					
	I can sense medium urgency situations while using the device					
	I can sense high urgency situations while using the device					
	I want to take action upon the color changes					
	I want to take action upon hearing the sounds					

Appendix B (Chapter 3)

B.1. Burst Design Evaluation Form (for 2 sets of bursts)

Test 1a: Learning/Confusion - Slow Down or Speed Up?

For each pair,

- indicate which sound advises you to slow down, and
- which sound advises you to speed up

Set 1

Pairs	Slow Down or Speed Up?	
1		
2		
3		







Set 2

Pairs	Slow Down or Speed Up?	
1		
2		
3		













Test 1b: Learning/Confusion - Which one is more urgent?

- There are 6 pairs in each set
- All of them specify the same message (either Slow Down or Speed Up)
- For each pair, indicate which sound is **more urgent** than the other

Set 1

Pairs	Which one is more urgent?	
1		
2		
3		
4		
5		
6		







Set 2

Pairs	Which one is more urgent?	
1		
2		
3		
4		
5		
6		







Test 2: Matching/Recognition - Label all properties!

- You will see all the sounds in a set, giving either Slow Down or Speed Up advice
- Each of the advice has 3 levels of urgency
 - Low (slow action)
 - Medium
 - High (fast action)

Set 1

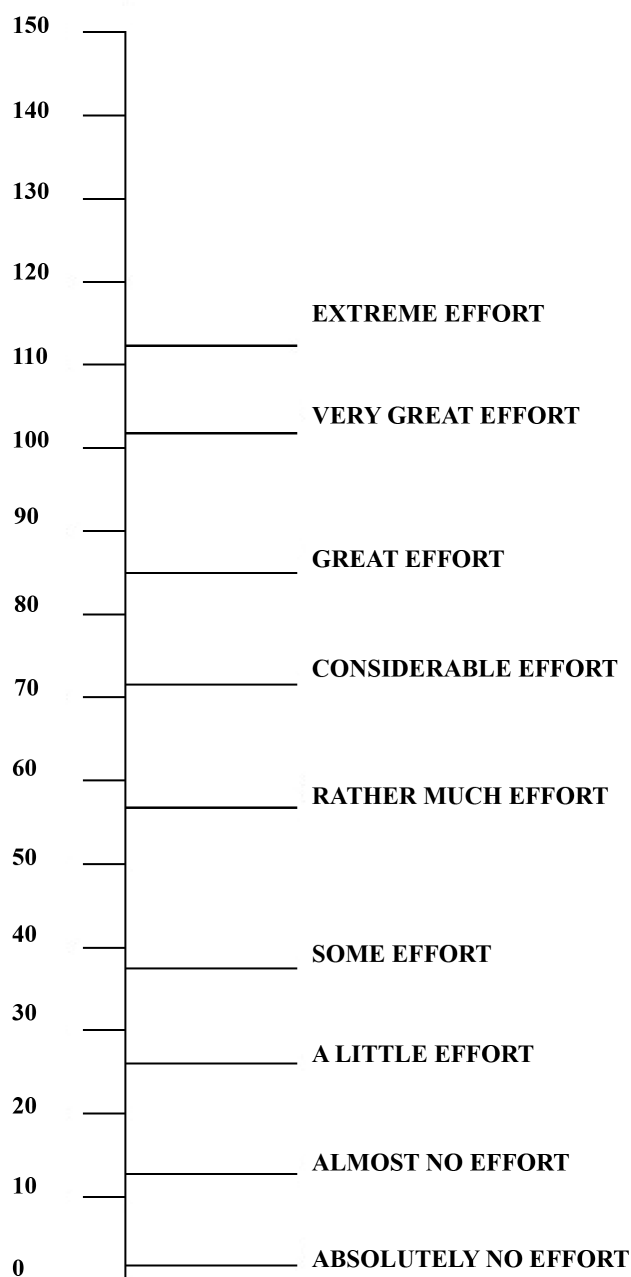
Sound	Slow Down / Speed Up?	Urgency (low/med/high)
		
		
		
		
		
		

Set 2

Sound	Slow Down / Speed Up?	Urgency (low/med/high)
		
		
		
		
		
		

B.2. Rating Scale Mental Effort (RSME)

Experiment participants are asked to point anywhere on the vertical line between 0 and 150 in order to rate their mental effort while performing a task. The point does not have to fall on the line's marker. Adjectives explaining their mental effort can be useful in helping participants decide the position of the point. In the rating measurement, the location of the point is calculated in proportion to the length of the vertical line (Zijlstra & van Doorn, 1985). For the purpose of the experiments in this thesis, a program written in Java (based on the work of Schedin (2003)) was used to allow experiment participants to mark the line easily using a computer mouse.



B.3. Appropriateness, Annoyance, Recognizability Rating

Concept & Prototype Ratings

Please rate 3 aspects from the auditory messages in relation to your interaction with them while driving.

* Required

Urgency recognition *

Did you recognize the difference in urgency levels conveyed by all auditory messages that you heard? Please rate from 0 (none) to 10 (all).

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

Annoyance *

Please rate the auditory messages from 0 (not annoying at all) to 10 (always annoying).

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

Appropriateness *

How appropriate do you think about the auditory messages for Cooperative Speed Assistance? Please rate from 0 (not appropriate at all) to 10 (fully appropriate).

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

For experimenter to fill *

Proto1, ConceptB

Appendix C (Chapter 4)

C.1. Van Der Laan Scale

(Van Der Laan et al., 1997)

★

1 2 3 4 5

Useful ☐ ☐ ☐ ☐ ☐ Useless

★

1 2 3 4 5

Pleasant ☐ ☐ ☐ ☐ ☐ Unpleasant

★

1 2 3 4 5

Bad ☐ ☐ ☐ ☐ ☐ Good

★

1 2 3 4 5

Nice ☐ ☐ ☐ ☐ ☐ Annoying

★

1 2 3 4 5

Effective ☐ ☐ ☐ ☐ ☐ Superfluous

★

1 2 3 4 5

Irritating ☐ ☐ ☐ ☐ ☐ Likeable

★

1 2 3 4 5

Assisting ☐ ☐ ☐ ☐ ☐ Worthless

★

1 2 3 4 5

Undesirable ☐ ☐ ☐ ☐ ☐ Desirable

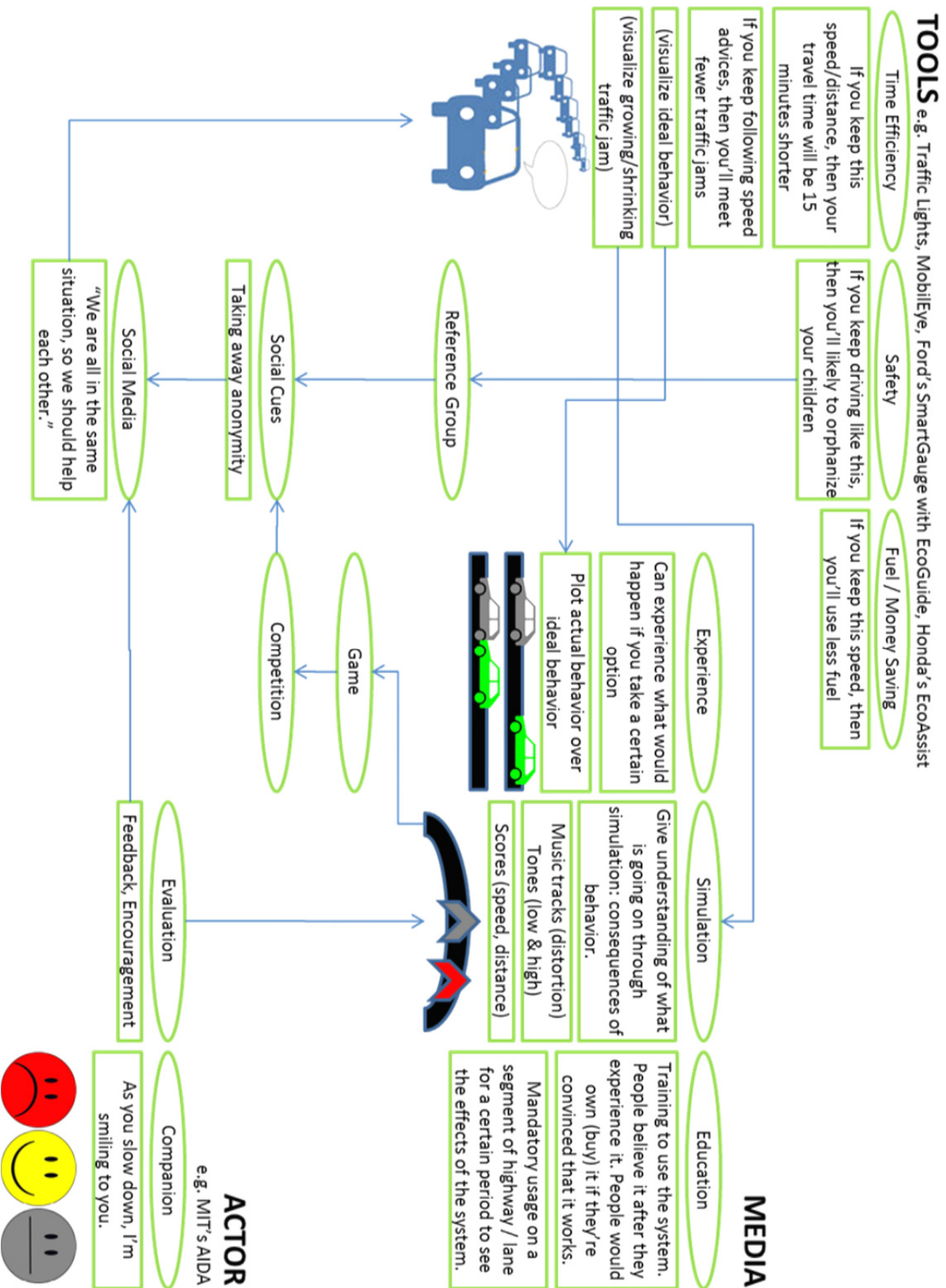
★

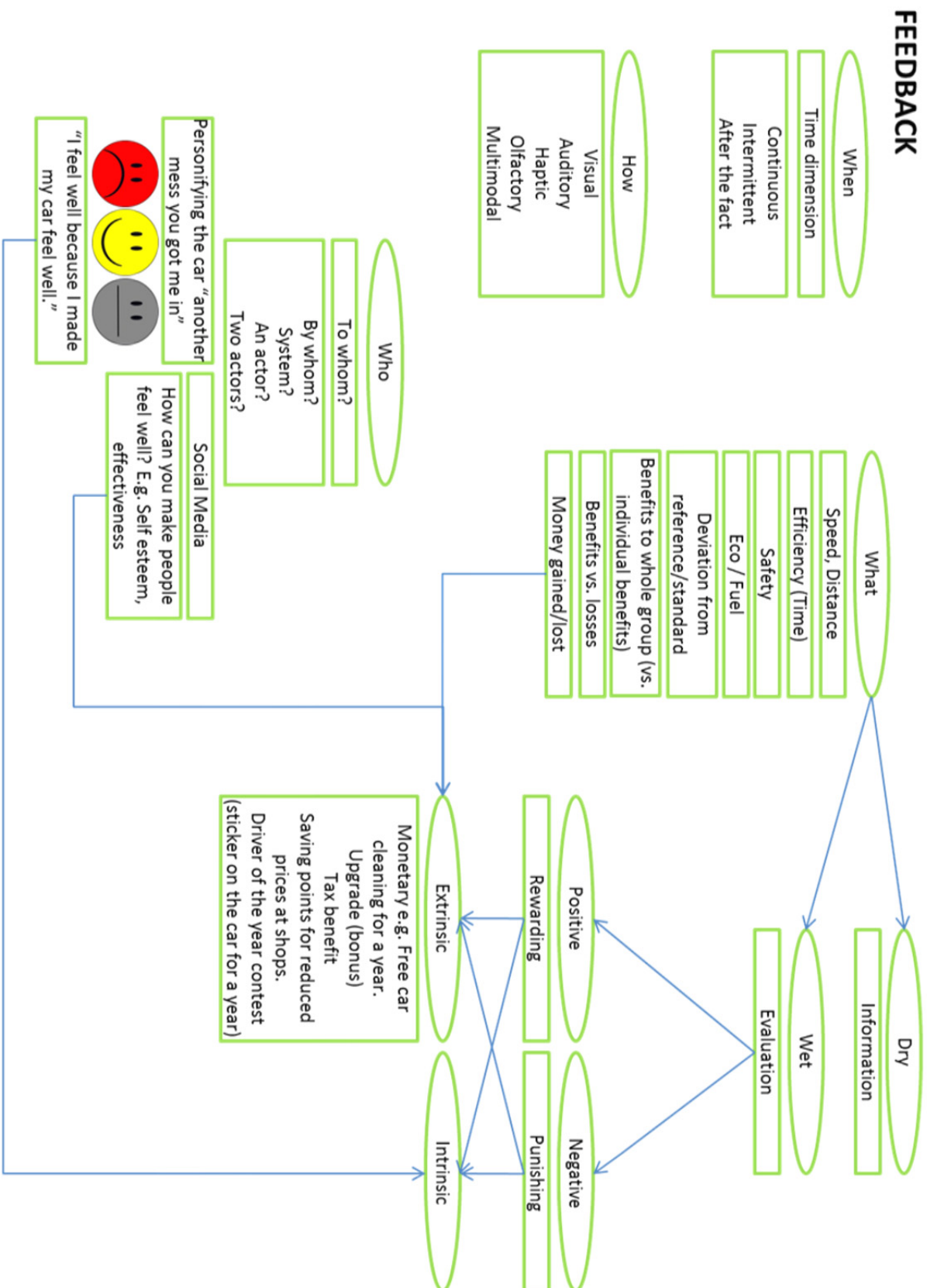
1 2 3 4 5

Raising alertness ☐ ☐ ☐ ☐ ☐ Sleep-inducing

Appendix D (Chapter 6)

D.1. Exploration on existing driving assistance technologies





Appendix E (Chapter 8)

E.1. PDV-Q Items and Responses by Game Participants

Table E.1. PDV-Q Items

PDV	Items
Relax	1. I drive slower because it's more relaxing.
Sustain	2. I drive slower because it produces less CO2 emission.
Safety	3. I drive slower when the speed limit goes down, because speed limits are intended to improve safety.
Fun	4. I drive faster because I love the adrenalin rush.
Time	5. I drive faster when I am late for an appointment.
Fun	6. I drive faster when there is less traffic, because driving fast is fun.
Relax	7. I stay on the safe side of the speed limit, because I feel more relaxed.
Time	8. I find traffic jams annoying, because I tend to depart on the last minute.
Sustain	9. I try to apply "eco driving" techniques (het "nieuwe rijden"), because it saves the environment.
Safety	10. I adjust my speed according to the matrix boards (electronic traffic signs), because it enables a smooth traffic flow.
Relax	11. I like driving behind another car, even if it's slow, because I find it relaxing.
Sustain	12. I try to drive as energy efficient as possible, because it's better for the environment.
Safety	13. I maintain a large distance to the car in front of me while driving, because it's more comfortable.
Fun	14. I overtake other cars, because it keeps me engaged.
Time	15. I overtake cars driving slower than I like to drive, because they slow me down.
Fun	16. I overtake cars driving slower than I like to drive, because it's boring to drive that slowly.
Sustain	17. When I drive I think about my car's CO2 emission, because I don't want to pollute the air.
Time	18. I find traffic jams annoying, because I hate getting late.
Fun	19. I drive really fast, because it is boring to drive in the highway.
Safety	20. I adjust my speed in dense traffic, because I don't want to cause accidents.
Sustain	21. I try to use the car only when it's needed, in order to save the environment.
Time	22. I drive more aggressively when I'm late because I get nervous of my own lateness.

Table E.2. PDV-Q Responses by Game Participants

ID	relax	sustain	safety	fun	time	max	stdev	average	sd+avg	profile
1	3.33	2.40	5.25	4.40	3.60	5.25	0.97	3.76	4.73	safety
2	4.00	4.00	5.75	2.40	5.40	5.75	1.20	4.36	5.56	safety
3	5.33	4.20	6.75	2.40	3.80	6.75	1.47	4.51	5.98	safety
4	3.33	4.40	6.50	4.00	5.60	6.50	1.14	4.77	5.91	safety
5	3.00	3.20	5.75	4.40	4.80	5.75	1.05	4.33	5.37	safety
6	3.67	6.20	6.50	4.20	5.80	6.50	1.13	5.29	6.42	safety
7	4.33	5.00	6.25	3.20	3.20	6.25	1.15	4.40	5.55	safety
8	1.67	3.80	5.25	4.80	6.20	6.20	1.60	4.52	6.12	time
9	3.00	3.00	5.00	3.80	4.60	5.00	0.87	4.00	4.87	safety
10	2.00	2.80	4.75	4.80	4.00	4.80	1.14	3.79	4.94	fun
11	4.00	2.60	5.50	2.20	4.60	5.50	1.33	3.98	5.31	safety
12	2.67	1.20	5.00	6.00	7.00	7.00	2.22	4.61	6.83	time
13	4.00	1.60	5.25	2.80	4.60	5.25	1.31	3.68	4.98	safety
14	3.00	4.80	6.25	5.20	5.80	7.00	1.38	5.34	6.73	safety
15	2.00	4.00	5.00	2.00	2.40	5.00	1.23	3.17	4.40	safety
16	3.33	4.00	6.00	6.40	4.80	6.40	1.24	5.09	6.33	fun
17	2.33	3.80	5.25	5.40	6.60	6.60	1.54	4.86	6.40	time
18	6.33	2.20	5.75	1.80	4.00	6.33	1.82	4.01	5.84	relax
19	2.67	2.20	6.00	5.20	4.80	6.00	1.54	4.34	5.88	safety
20	3.67	1.40	5.50	5.00	5.80	5.80	1.68	4.46	6.14	time
21	3.33	3.00	6.50	3.80	3.40	6.50	1.27	4.04	5.31	safety
22	4.67	2.20	5.00	3.60	4.20	5.00	1.02	4.04	5.07	safety
23	2.67	1.60	5.00	3.80	5.80	5.80	1.60	3.98	5.58	time
24	3.67	3.80	5.75	1.40	4.80	5.75	1.61	4.17	5.78	safety
25	4.67	4.00	6.75	2.80	3.20	6.75	1.39	4.30	5.70	safety
26	2.67	3.20	5.25	4.40	4.40	5.25	0.94	4.05	5.00	safety
27	2.67	1.00	5.75	2.40	3.80	5.75	1.65	3.30	4.95	safety
28	2.33	4.20	5.75	3.20	2.40	5.75	1.28	3.58	4.86	safety

Table E.3. Scores of PDV-Q items constituting Safety profile, as measured pre-test and post-test

Code	Statement	Correlated	Different
Q3	I drive slower when the speed limit goes down, because speed limits are intended to improve safety.	No	Pre > Post
Q10	I adjust my speed according to the matrix boards (electronic traffic signs), because it enables a smooth traffic flow.	Yes, moderate	Pre > Post
Q13	I maintain a large distance to the car in front of me while driving, because it's more comfortable.	Yes, moderate	No
Q20	I adjust my speed in dense traffic, because I don't want to cause accidents.	No	No

E.2. Game Rules, Story, and Settings

Welcome to SNELWEG2020!

You live in the Netherlands, the year 2020.

Just like the current highways, in 2020 the highways still have the same rules:

- Left lane is for overtaking, while right lane is for slower vehicles
- Default speed limit is 120 km/h, and temporary speed limits are broadcasted digitally
- You get a fine if you exceed the default speed limit

Just like the current navigation system, in 2020 you still use one:

- It tells you when/where to turn
- It tells you when you got caught by the speed cameras (speed cameras are sneaky!)

Game Scoring:

- Reach your destination as guided by the navigation system
- Reach your destination faster, and you'll get bonus points! Compete with other players!

What costs what?

- You have 30 Euro at the beginning of the game
- Speed limit fine is 0.1 Euro (10 cents)
- If you crash, the insurance company asks you 1 Euro excess payment

HAVE FUN!

Figure E.1. Game rules explained to the participants at the beginning of the game

The Story...

Drive with the ducks!
 The ducks are not scary, they're your companion on the road 😊
 Follow them or not, it's all up to you.

Figure E.2. A poster about the game fantasy, shown to participants at the beginning of the game

Table E.4. Description of each game level: difficulty of the course, feedback given to players, and general observation of players' behavior

Game Levels	Traffic Difficulty	Speed Advice	Platoon Speed (km/h)	Player's Response
1	Normal: faster cars (140km/h) on the left lane, (slower) platoons on the right lane. Medium route.	None	70 110	
2	If player moves to the left lane, the cars slow down (30km/h) causing traffic jam. Medium route.	(same as above)	(same as above)	Players overtook from the right and went back to the left, leaving traffic behind
3	If player moves to the left lane, the cars slow down causing traffic jam. Medium route.	Only on the right lane (behind platoon)	(same as above)	(same as above)
4	Continuously busy traffic on the left lane. Long route.	On both lanes	80 120	Players spent more time on the right lane
5	(same as above)	(same as above)	(same as above)	Players overtook from the emergency / exit lane
6	Continuously busy traffic on the left lane. Medium route.	(same as above)	(same as above)	(same as above)
7	Continuously busy traffic on the left lane. Heavy traffic overall. Short route.	(same as above)	(same as above)	(same as above)
8	Continuously busy traffic on the left lane. Heavy traffic overall. Raining. Short route.	(same as above)	(same as above)	(same as above)

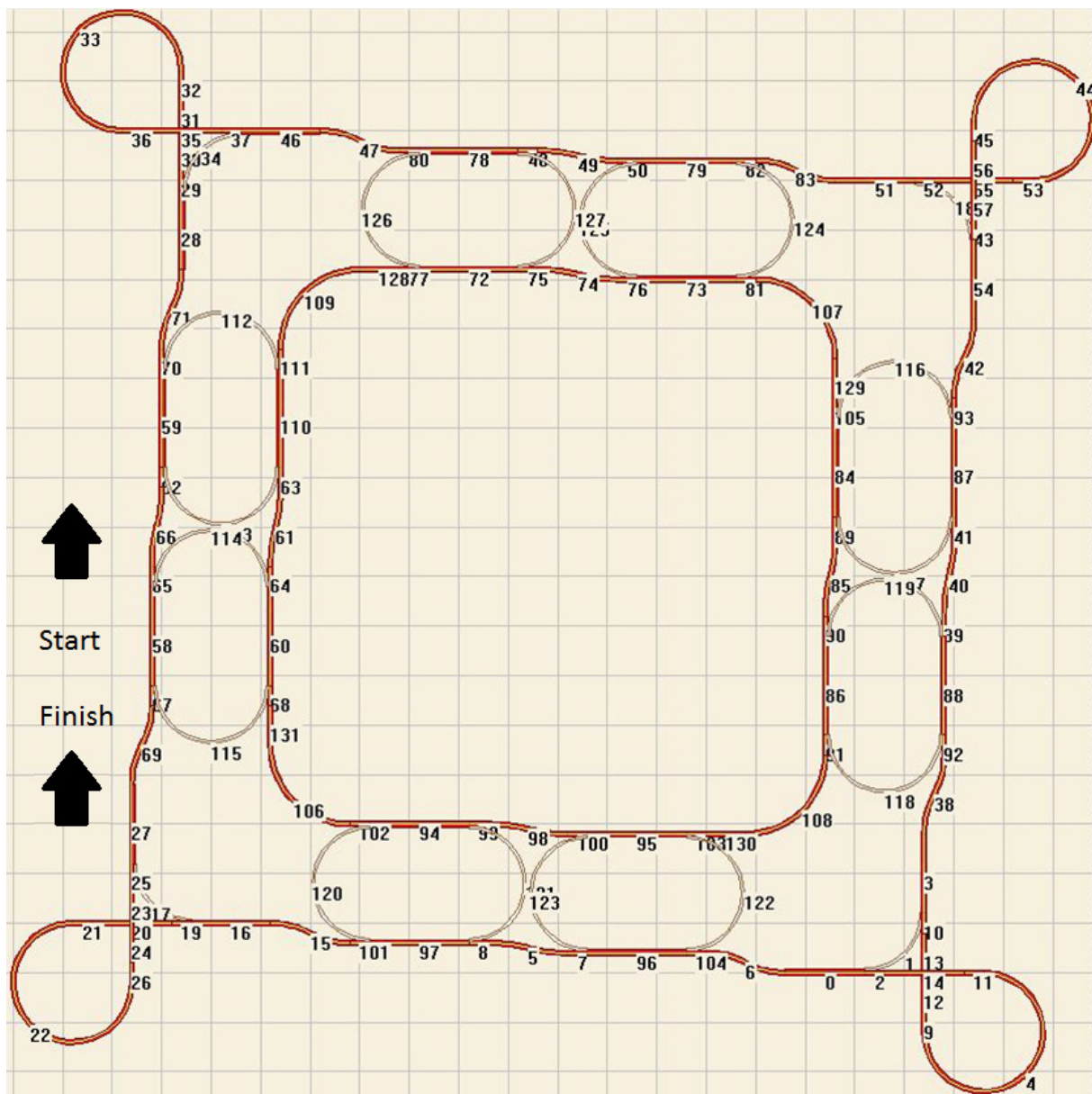


Figure E.3 The maps of Snelweg3 track as provided by Greendino

Short route: from Segment 58 through different turns (inner road) until Segment 67, without any circular ramps. Total 18340 meters.

Medium route: from Segment 58 through only the outer road until Segment 67, including the four circular ramps. Total 24000 meters.

Long route: from Segment 58 through different turns (inner road) until Segment 67, including two circular ramps. Total 27010 meters.

Table E.6. Speed segments in Phase1,
Speed advices in Phase 2

Segment No.	Length(m)	Speed Limits(km/h)
58	500	80
65	500	120
62	600	80
70	900	120
29	600	80
33	1400	120
36	500	80
37	500	120
47	500	80
78	1000	120
50	600	80
82	900	120
52	500	80
53	1500	120
45	500	80
43	500	120
42	500	80
87	1000	120
39	600	80
92	900	120
10	600	80
4	1400	120
11	500	80
2	900	120
104	600	80
7	500	120
8	600	80
101	900	120
19	600	80
22	1400	120
26	500	80
25	1000	120
Total	24000	

Table E.7. Speed advices in Phase 3

Segment No.	Length (m)	Speed Limits(km/h)	PM
58	500	80	
65	600	120	
59	600	80	relax
71	800	120	
29	600	80	time
33	1400	120	
36	600	80	fun
46	800	120	
80	600	80	time
48	600	120	
79	500	80	sustain
124	900	100	
73	600	80	safety
74	500	120	
72	600	80	fun
128	820	120	
111	600	80	safety
63	500	120	
64	600	80	time
68	300	120	
106	620	80	relax
102	600	120	
99	500	80	time
100	500	120	
95	600	80	fun
130	820	120	
91	600	80	sustain
119	900	100	
39	600	80	safety
92	500	120	
3	400	80	sustain
1	450	100	
0	800	80	safety
104	600	120	
7	500	80	relax
8	600	120	
101	500	80	fun
16	400	120	
19	600	80	sustain
22	1400	120	
26	500	80	relax
25	1000	120	
Total	27010		

Table E.8. Speed Limits in Phase 4 (PM group)

Segment No.	Length (m)	Speed Limits(km/h)	PM
58	500	80	
65	1100	120	
112	900	100	
110	600	80	safety
61	1100	120	
131	200	110	time
106	620	100	time
102	2200	120	
130	200	110	time
108	620	100	time
91	1700	120	
116	900	100	
87	600	80	safety
40	1900	120	
1	450	100	
0	800	80	safety
104	2600	120	
17	450	100	
27	800	80	relax
67	100	120	
Total	18340		

Table E.9. Speed Limits in Phase 4 (Money group)

Segment No.	Length (m)	Speed Limits(km/h)	PM
58	500	80	
65	1100	120	
112	900	100	
110	600	80	money
61	1100	120	
131	200	110	money
106	620	100	money
102	2200	120	
130	200	110	money
108	620	100	money
91	1700	120	
116	900	100	
87	600	80	money
40	1900	120	
1	450	100	
0	800	80	money
104	2600	120	
17	450	100	
27	800	80	money
67	100	120	
Total	18340		

In Levels 1 – 3, all platoons drove 10 km/h below the speed limit.

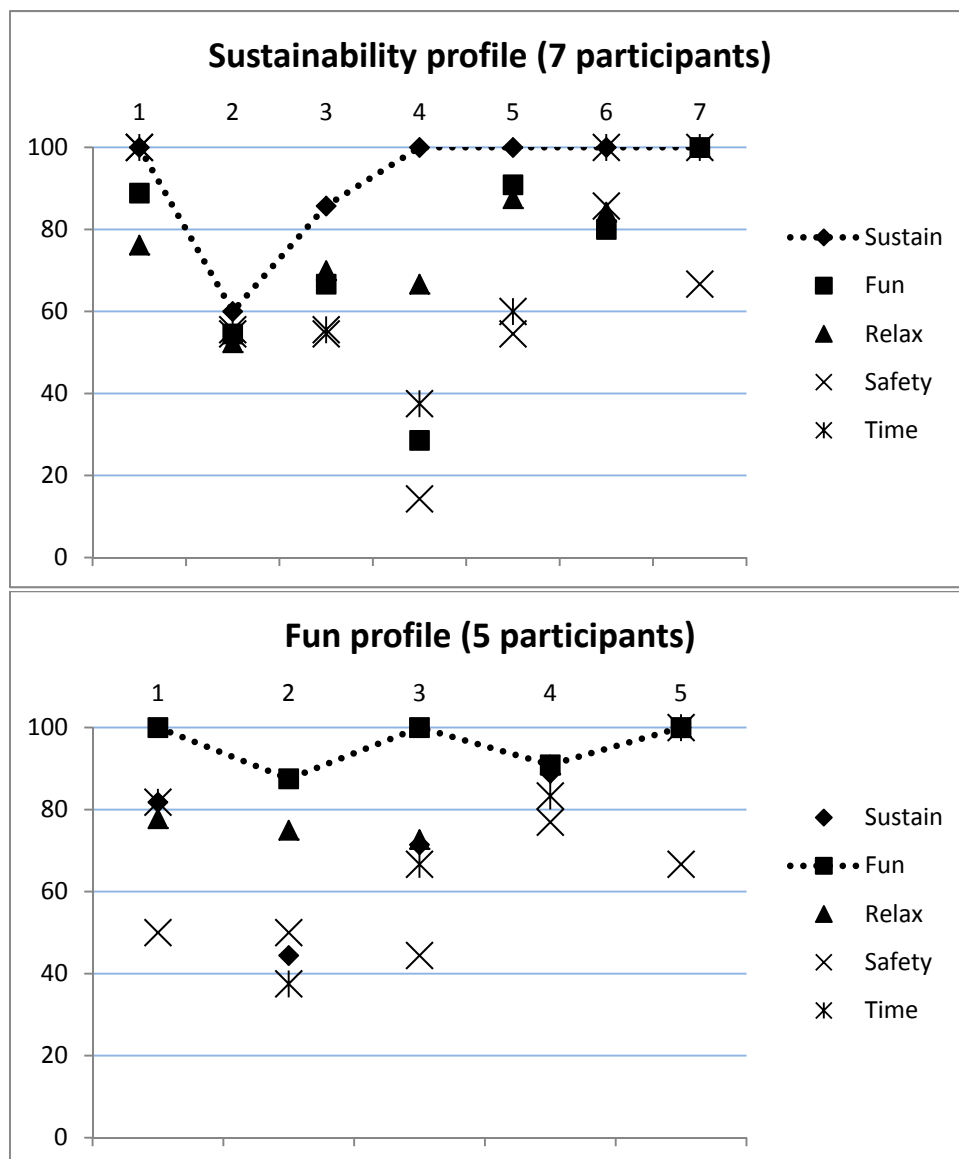
In Levels 4 – 8, all platoons drove at the speed limit.

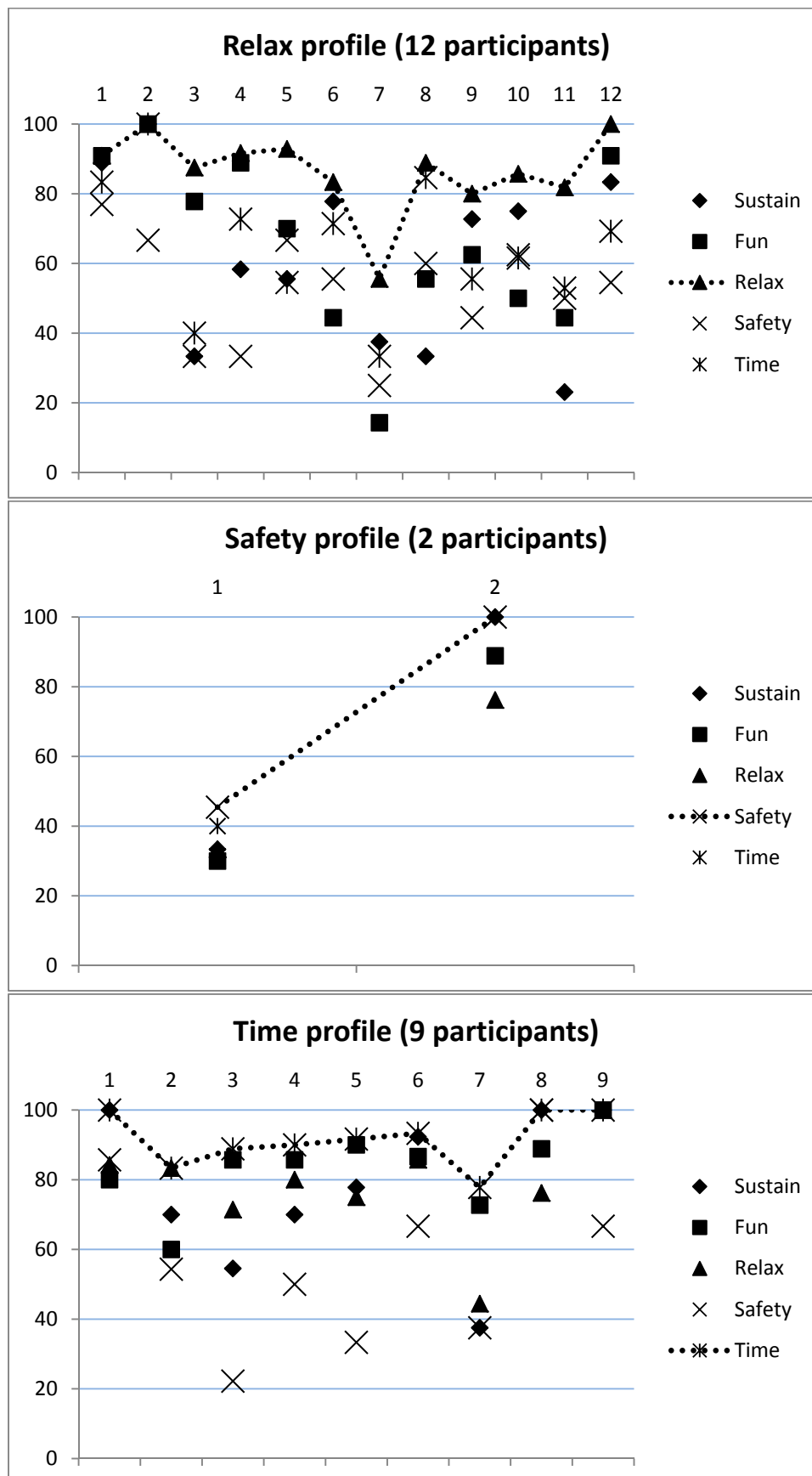
In Levels 1 – 8, all cars on the left drove 20 km/h above the speed limit.

E.3. Details of Objective Profiles taken from Phase 3

E.3.1. Based on Right Lane Choice

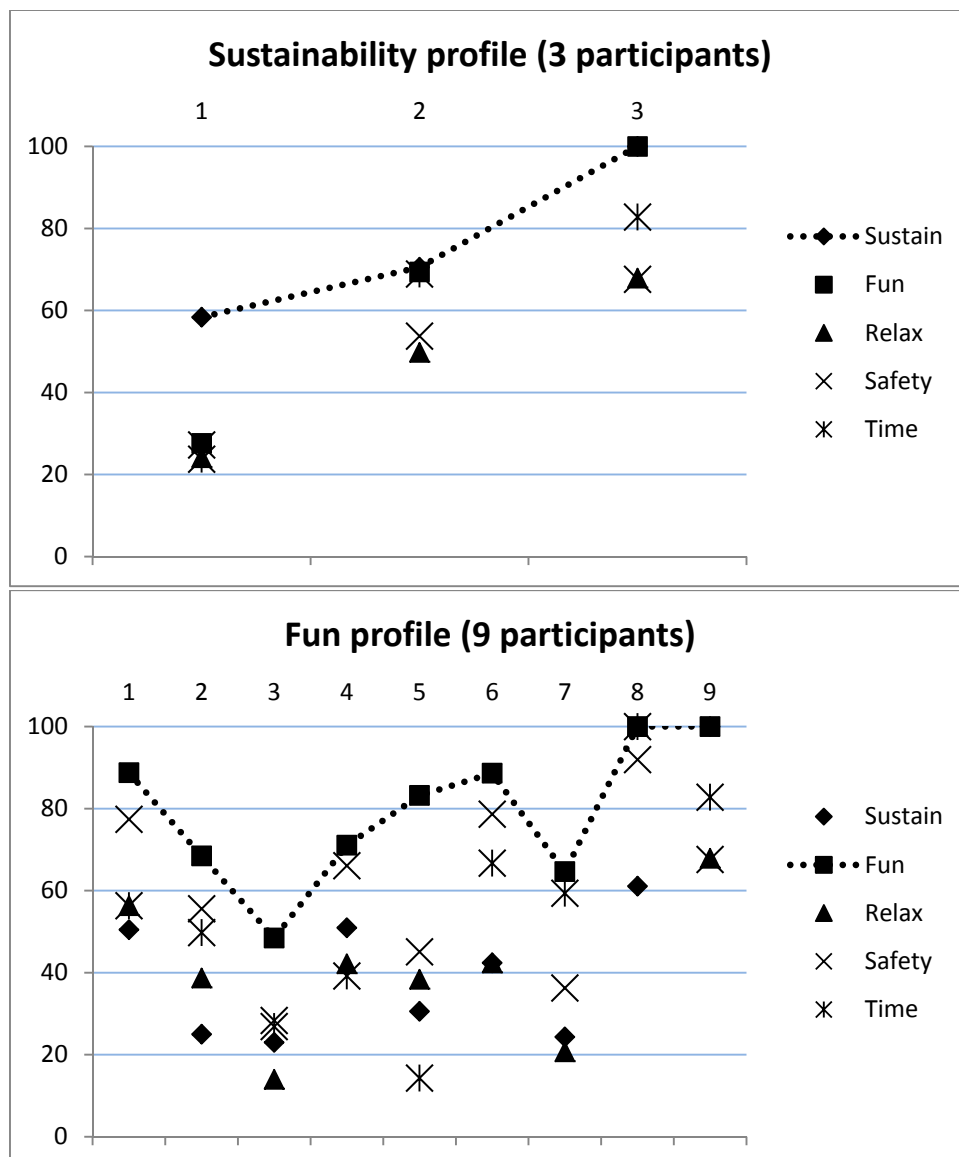
This section outlines the details of behavioral response toward persuasive messages in Phase 3 based on right lane choice. The persuasion profiles are determined by the strongest response toward messages representing the corresponding persuasion strategy. The strongest response is derived from the highest percentage of right lane choice for a message over all other lane choices. The five charts show that for each participant, the strongest response for a persuasion strategy is not very different from the responses to other persuasion strategies. The distinct one is shown in the Sustainability chart, participant no. 4.

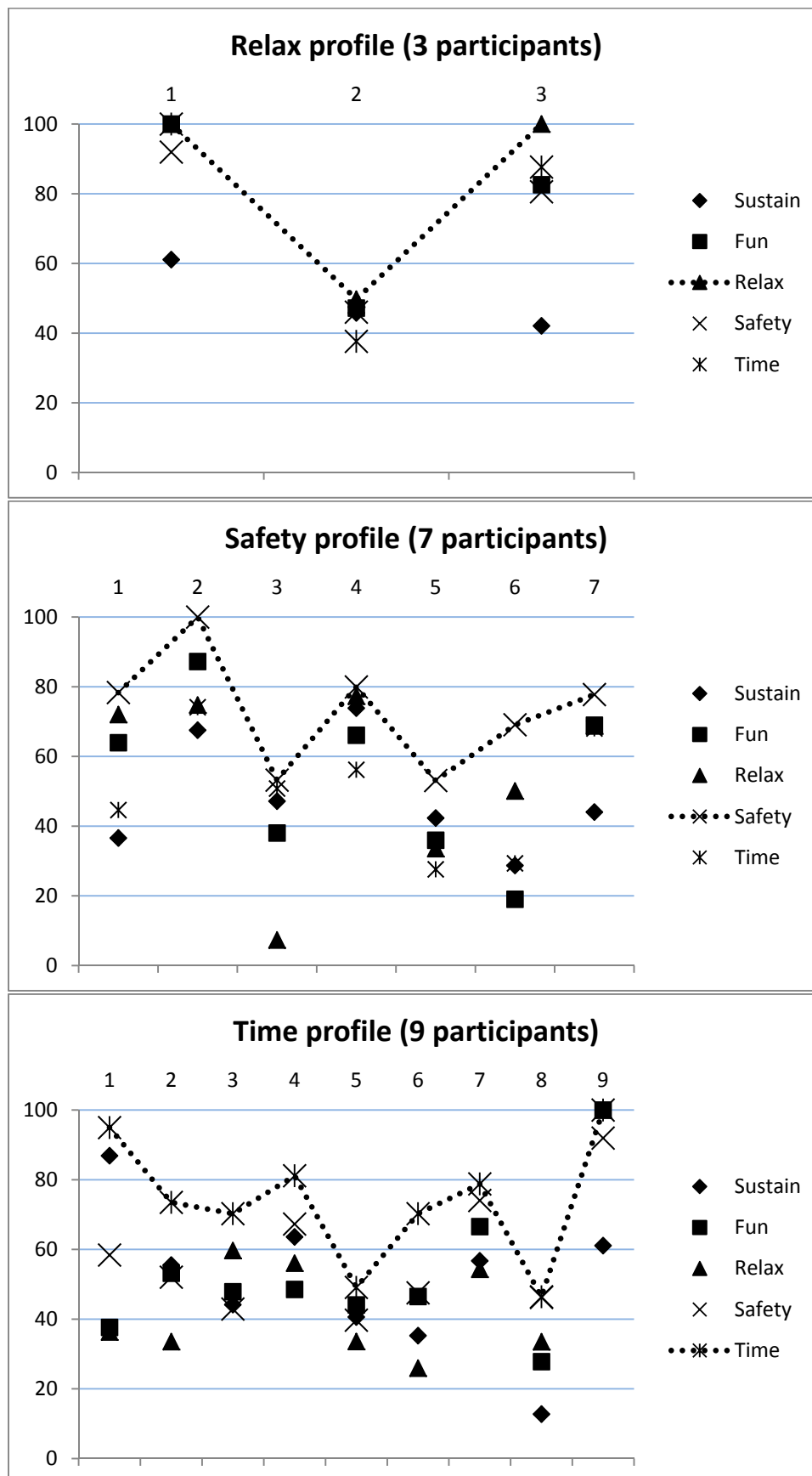




E.3.2. Based on Right Lane Duration

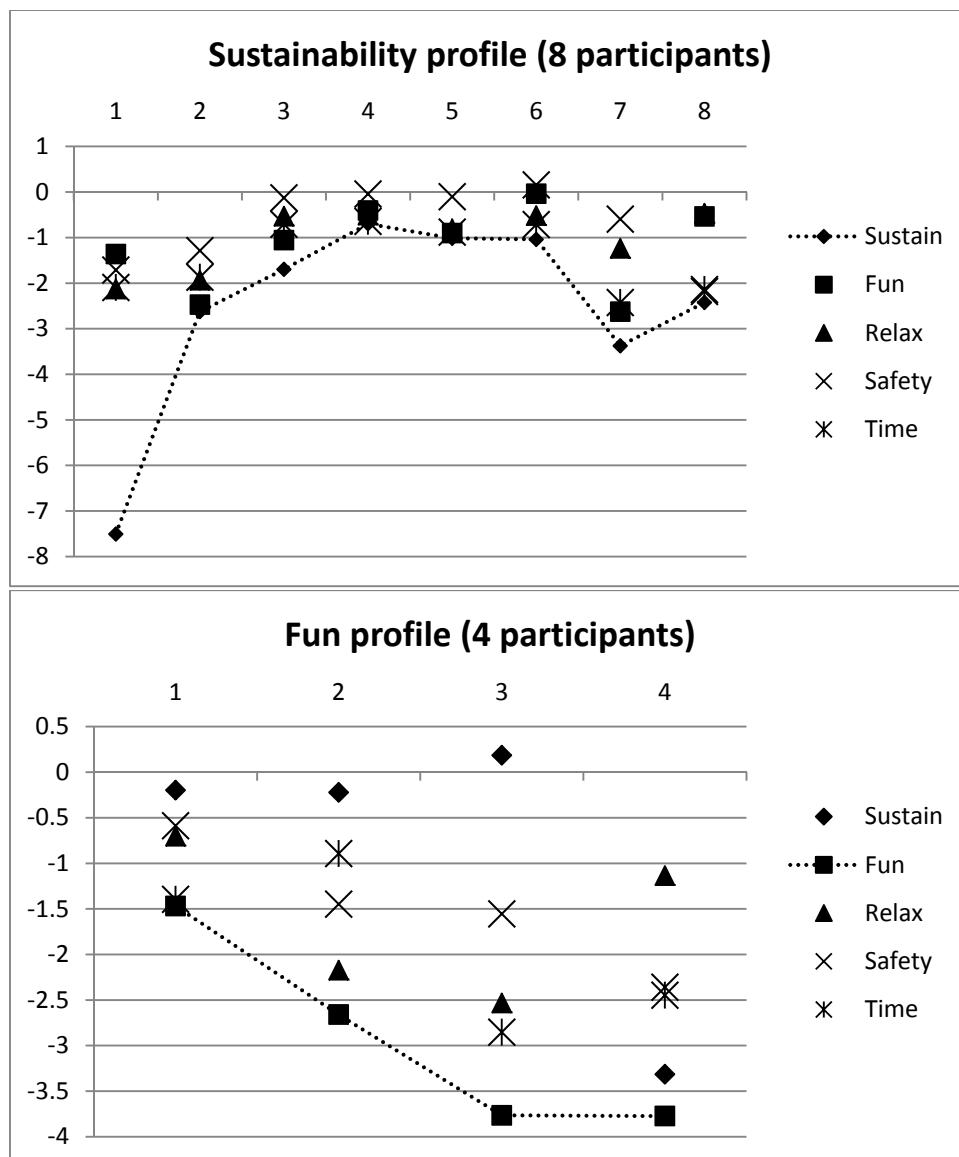
This section outlines the details of behavioral response toward persuasive messages in Phase 3 based on right lane duration. The persuasion profiles are determined by the strongest response toward messages representing the corresponding persuasion strategy. The strongest response is derived from the highest percentage of duration of staying on the right lane while receiving a message over the duration of staying on other lanes. The five charts show that for each participant, the strongest response for a persuasion strategy is not very different from the responses to other persuasion strategies. The distinct one is shown in the Sustainability chart, participant no. 1.

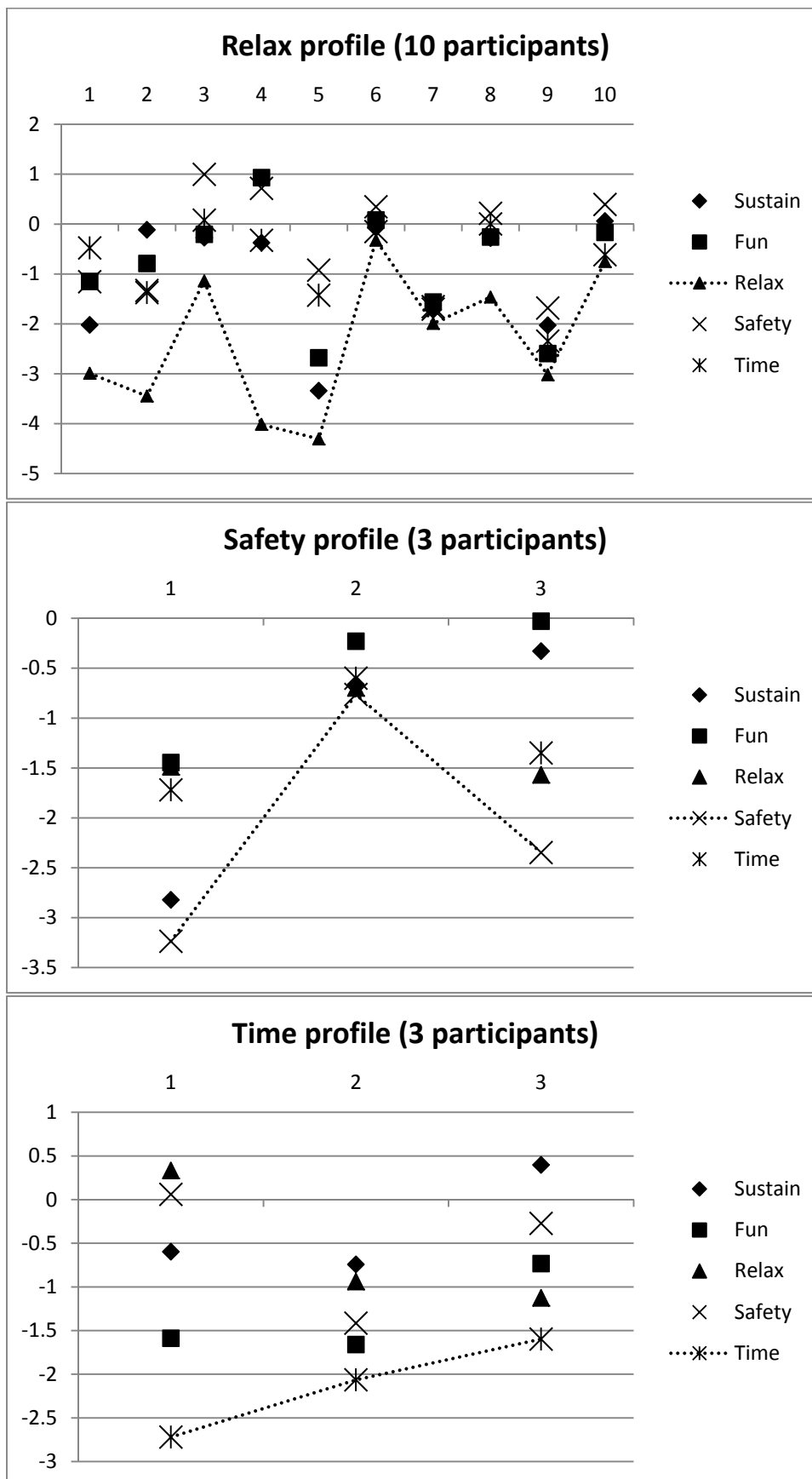




E.3.3. Based on Speed Response Slope

This section outlines the details of behavioral response toward persuasive messages in Phase 3 based on speed response slope. The persuasion profiles are determined by the strongest response toward messages representing the corresponding persuasion strategy. The strongest response is derived from the steepest slope in speed response toward a message. The five charts show that for each participant, the strongest response for a persuasion strategy is not very different from the responses to other persuasion strategies. The distinct one is shown in the Sustainability chart, participant no.1.





E.4. Comparison of Objective Profiles between Phase 3 and Phase 4

Based on subjective preferences at the end of Phase 3 there was no Fun message for PM group in Phase 4. Therefore, participants with Fun profiles based on PDV-Q were not included in this analysis. Out of the 16 participants in the PM group, only 14 participants were included in this comparison. Based on right lane choice, only 6 out of 14 participants were consistent between Phase 3 and Phase 4. Based on right lane duration, only 1 out of 14 participants were consistent between Phase 3 and Phase 4. Based on steepest speed response slope, only 3 out of 14 participants were consistent between Phase 3 and Phase 4.

Table E.10. Highest percentage of right lane choice in Phase 3 and Phase 4

Participants	PDV-Q	Phase3	Phase4
user02	safety	time	relax/safety/time
user04	safety	fun	time
user05	safety	sustain	safety/sustain
user06	safety	fun/relax/sustain/time	sustain
user07	safety	sustain/time	safety
user14	safety	fun	safety/sustain
user15	safety	relax	relax/time
user17	time	sustain	safety
user19	safety	relax	safety
user21	safety	sustain	relax/safety
user22	safety	relax	relax
user24	safety	relax	relax/safety
user26	safety	time	relax
user27	safety	time	safety

Table E.11. Highest percentage of right lane duration in Phase 3 and Phase 4

Participants	PDV-Q	Phase3	Phase4
user02	safety	time	time
user04	safety	fun	relax
user05	safety	safety	sustain
user06	safety	fun/relax/time	safety
user07	safety	safety	relax
user14	safety	fun	safety
user15	safety	relax	safety
user17	time	time	safety
user19	safety	safety	time
user21	safety	fun	safety
user22	safety	time	relax
user24	safety	time	safety
user26	safety	safety	relax
user27	safety	relax	time

Table E.12. Steepest speed response slope in Phase 3 and Phase 4

Participants	PDV-Q	Phase3	Phase4
user02	safety	fun	safety
user04	safety	time	relax
user05	safety	relax	safety
user06	safety	sustain	safety
user07	safety	safety	relax
user14	safety	safety	time
user15	safety	safety	safety
user17	time	sustain	time
user19	safety	relax	relax
user21	safety	sustain	time
user22	safety	relax	time
user24	safety	sustain	relax
user26	safety	time	relax
user27	safety	relax	relax

Glossary

ACC	Adaptive Cruise Control, a cruise control that adapts speed while keeping specified distance to the preceding vehicle
ADAS	Advanced Driver Assistance System
C-ACC	Cooperative Adaptive Cruise Control, an extension of ACC, where wireless communication allows V2V in a wider range and also V2I
CSA	Cooperative Speed Assistance
Gap	The difference between the front of a vehicle and the back of a preceding vehicle traveling in the same direction. Distance Gap is measured in space (meter), Time Gap is measured in time (second).
Headway	The difference between the front of a vehicle and the front of a preceding vehicle traveling in the same direction. Distance Headway is measured in space (meter), Time Headway is measured in time (second).
ISA	Intelligent Speed Adaptation
MAO	Motivation-Ability-Opportunity
Mental workload	The perceived relationship between the amount of mental processing capability or resources and the amount required by the task
Mental overload	Sustained high mental workload
Mental underload	Sustained low mental workload
Nomadic system	Non built-in or portable system transferable to different vehicles and/or installable in different devices, e.g. smartphone applications
PND	Portable Navigation Device
TPB	Theory of Planned Behavior
V2I	Vehicle to Infrastructure communication, through wireless communication, between a vehicle and the road infrastructure such as traffic controller
V2V	Vehicle to Vehicle communication, through sensors (between two adjacent vehicles) or through wireless communication (between several vehicles in a platoon)
V2X	Vehicle to everything communication

Acknowledgements

I got my driving license when I was a teenager, and all I knew then was how to maximize the possibility of driving fast without violating the traffic laws. I never thought I would study a driver assistance system and driver behavior. When I was a trainee at the USI program, I applied for this PhD position because of my affinity toward Persuasive Technology, instead of toward driving. During the PhD I learned that there is more to traffic regulation than just the traffic laws. The wide variety of driver behavior causes irregularities in highway traffic. Now, I do not drive the same way I used to drive. Yet I still enjoy driving!

I am very grateful to have worked under the supervision of Jacques Terken, who inspired me with his expertise in cognitive psychology and experiment design. I have also improved my writing skill thanks to his generous linguistic inputs. I treasure our conversations, personal and work-related, serious and funny.

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I hope you enjoy reading (or having) this book!

Eindhoven, 24 March 2014

“Treat others as you want to be treated”
- The Golden Rule -