Automotive User Interfaces for the Support of Non-Driving-Related Activities

Bastian Pfleging

University of Stuttgart

Automotive User Interfaces for the Support of Non-Driving-Related Activities

Von der Fakultät für Informatik, Elektrotechnik und Informationstechnik der Universität Stuttgart und dem Stuttgart Research Centre for Simulation Technology (SRC SimTech) zur Erlangung der Würde eines Doktors der Naturwissenschaften (Dr. rer. nat.) genehmigte Abhandlung

Vorgelegt von

Dipl.-Inf. Bastian Pfleging

aus Hagen

Hauptberichter:	Prof. Dr. Albrecht Schmidt
Mitberichter:	Prof. Andrew L. Kun, PhD
Mitberichter:	Univ.-Prof. Dr. Manfred Tscheligi
Tag der mündlichen Prüfung:	11.04.2016

Institut für Visualisierung und Interaktive Systeme
der Universität Stuttgart

2017

ABSTRACT

When cars were invented, they allowed the driver and potential passengers to get to a distant location. The only activities the driver was able and supposed to perform were related to maneuvering the vehicle, i.e., accelerate, decelerate, and steer the car. Today drivers perform many activities that go beyond these driving tasks. This includes for example activities related to driving assistance, location-based information and navigation, entertainment, communication, and productivity. To perform these activities, drivers use functions that are provided by in-vehicle information systems in the car. Many of these functions are meant to increase driving safety or to make the ride more enjoyable. The latter is important since people spend a considerable amount of time in their cars and want to perform similar activities like those to which they are accustomed to from using mobile devices. However, as long as the driver is responsible for driving, these activities can be distracting and pose driver, passengers, and the environment at risk. One goal for the development of automotive user interfaces is therefore to enable an easy and appropriate operation of in-vehicle systems such that driving tasks and non-driving-related activities can be performed easily and safely.

The main contribution of this thesis is a set of guidelines and exemplary concepts for automotive user interfaces that offer safe, diverse, and easy-to-use means to perform also non-driving-related activities while driving. Using empirical methods that are commonly used in human-computer interaction, we approach various aspects of automotive user interfaces in order to support the design and development of future interfaces that also enable non-driving-related activities. Starting with manual, non-automated driving, we also consider the transition towards automated driving modes.

As a first part, we look at the prerequisites that enable non-driving-related activities in the car. We propose guidelines for the design and development of automotive user interfaces that also support non-driving-related activities. This includes for instance rules on how to adapt or interrupt activities when the level of automation changes. To enable activities in the car, we propose a novel interaction concept that facilitates multimodal interaction in the car by combining speech interaction and touch gestures. Moreover, we reveal aspects on how to infer information about the driver's state (especially mental workload) by using physiological data. We conducted a real-world driving study to extract a data set with physiological and context data. This can help to better understand the driver state, to adapt interfaces to the driver and driving situations, and to adapt the route selection process.

Second, we propose two concepts for supporting non-driving-related activities that are frequently used and demanded in the car. For telecommunication, we propose a concept to increase driving safety when communicating with the outside world. This concept enables the driver to share different types of information with remote parties. Thereby, the driver can choose between different levels of details ranging from abstract information such as “Alice is driving right now” up to sharing a video of the driving scene. We investigated the drivers’ needs on the go and derived guidelines for the design of communication-related functions in the car through an online survey and in-depth interviews. As a second aspect, we present an approach to offer time-adjusted entertainment and productivity tasks to the driver. The idea is to allow time-adjusted tasks during periods where the demand for the driver’s attention is low, for instance at traffic lights or during a highly automated ride. Findings from a web survey and a case study demonstrate the feasibility of this approach.

With the findings of this thesis we envision to provide a basis for future research and development in the domain of automotive user interfaces and non-driving-related activities in the transition from manual driving to highly and fully automated driving.

Zusammenfassung

Als das Auto erfunden wurde, ermöglichte es den Insassen hauptsächlich, entfernte Orte zu erreichen. Die einzigen Tätigkeiten, die Fahrerinnen und Fahrer während der Fahrt erledigen konnten und sollten, bezogen sich auf die Steuerung des Fahrzeugs. Heute erledigen die Fahrerinnen und Fahrer diverse Tätigkeiten, die über die ursprünglichen Aufgaben hinausgehen und sich nicht unbedingt auf die eigentliche Fahraufgabe beziehen. Dies umfasst unter anderem die Bereiche Fahrerassistenz, standortbezogene Informationen und Navigation, Unterhaltung, Kommunikation und Produktivität. Informationssysteme im Fahrzeug stellen den Fahrerinnen und Fahrern Funktionen bereit, um diese Aufgaben auch während der Fahrt zu erledigen. Viele dieser Funktionen verbessern die Fahrsicherheit oder dienen dazu, die Fahrt angenehm zu gestalten. Letzteres wird immer wichtiger, da man inzwischen eine beträchtliche Zeit im Auto verbringt und dabei nicht mehr auf die Aktivitäten und Funktionen verzichten möchte, die man beispielsweise durch die Benutzung von Smartphone und Tablet gewöhnt ist. Solange der Fahrer selbst fahren muss, können solche Aktivitäten von der Fahrtätigkeit ablenken und eine Gefährdung für die Insassen oder die Umgebung darstellen. Ein Ziel bei der Entwicklung automobiler Benutzungsschnittstellen ist daher eine einfache, adäquate Bedienung solcher Systeme, damit Fahraufgabe und Nebentätigkeiten gut und vor allem sicher durchgeführt werden können.

Der Hauptbeitrag dieser Arbeit umfasst einen Leitfaden und beispielhafte Konzepte für automobile Benutzungsschnittstellen, die eine sichere, abwechslungsreiche und einfache Durchführung von Tätigkeiten jenseits der eigentlichen Fahraufgabe ermöglichen. Basierend auf empirischen Methoden der Mensch-Computer-Interaktion stellen wir verschiedene Lösungen vor, die die Entwicklung und Gestaltung solcher Benutzungsschnittstellen unterstützen. Ausgehend von der heute üblichen nicht automatisierten Fahrt betrachten wir dabei auch Aspekte des automatisierten Fahrens.

Zunächst betrachten wir die notwendigen Voraussetzungen, um Tätigkeiten jenseits der Fahraufgabe zu ermöglichen. Wir stellen dazu einen Leitfaden vor, der die Gestaltung und Entwicklung von automobilen Benutzungsschnittstellen unterstützt, die das Durchführen von Nebenaufgaben erlauben. Dies umfasst zum Beispiel Hinweise, wie Aktivitäten angepasst oder unterbrochen werden können, wenn sich der Automatisierungsgrad während der Fahrt ändert. Um Aktivitäten im Auto zu unterstützen, stellen wir ein neuartiges Interaktionskonzept vor, das eine multimodale Interaktion im Fahrzeug mit Sprachbefehlen und Touch-Gesten ermöglicht. Für automatisierte Fahrzeugsysteme und zur Anpassung der Interaktionsmöglichkeiten an die Fahrsituation stellt der Fahrerzustand (insbesondere

die mentale Belastung) eine wichtige Information dar. Durch eine Fahrstudie im realen Straßenverkehr haben wir einen Datensatz generiert, der physiologische Daten und Kontextinformationen umfasst und damit Rückschlüsse auf den Fahrerzustand ermöglicht. Mit diesen Informationen über Fahrerinnen und Fahrer wird es möglich, den Fahrerzustand besser zu verstehen, Benutzungsschnittstellen an die aktuelle Fahrsituation anzupassen und die Routenwahl anzupassen.

Außerdem stellen wir zwei konkrete Konzepte zur Unterstützung von Nebentätigkeiten vor, die schon heute regelmäßig bei der Fahrt getätigt oder verlangt werden. Im Bereich der Telekommunikation stellen wir dazu ein Konzept vor, das die Fahrsicherheit beim Kommunizieren mit Personen außerhalb des Autos erhöht. Das Konzept erlaubt es dem Fahrer, unterschiedliche Arten von Kontextinformationen mit Kommunikationspartnern zu teilen. Dies reicht von der abstrakten Information, dass man derzeit im Auto unterwegs ist bis hin zum Teilen eines Live-Videos der aktuellen Fahrsituation. Diesbezüglich haben wir über eine Web-Umfrage und detaillierte Interviews die Bedürfnisse der Nutzer(innen) erhoben und ausgewertet. Zudem stellen wir ein prototypisches Konzept sowie Richtlinien vor, wie künftige Kommunikationsaufgaben im Fahrzeug gestaltet werden sollen. Als ein zweites Konzept betrachten wir zeitbeschränkte Aufgaben zur Unterhaltung und Produktivität im Fahrzeug. Die Idee ist hier, zeitlich begrenzte Aufgaben in Zeiten niedriger Belastung zuzulassen, wie zum Beispiel beim Warten an einer Ampel oder während einer hochautomatisierten (Teil-) Fahrt. Ergebnisse aus einer Web-Umfrage und einer Fallstudie zeigen die Machbarkeit dieses Ansatzes auf.

Mit den Ergebnissen dieser Arbeit soll eine Basis für künftige Forschung und Entwicklung gelegt werden, um im Bereich automobiler Benutzungsschnittstellen insbesondere nicht-fahr-bezogene Aufgaben im Übergang zwischen manuellem Fahren und einer hochautomatisierten Autofahrt zu unterstützen.

PREFACE

This thesis is the result of the research I carried out at the University of Duisburg-Essen, the University of Stuttgart, and the University of Munich (LMU). As a dissertation can and should not be created in isolation, all of my decisions were influenced by innumerable conversations and discussions with my colleagues and students at all three universities as well as with various researchers that work on the topic of automotive user interfaces. Working as a research associate and PhD student at these universities, I supervised various final student projects including Bachelor, Master, and Diploma theses that were related to my research topic and which supported me in realizing my ideas. During all phases of my work, I enjoyed the invaluable and inspiring scientific exchange with researchers and practitioners at conferences, workshops, doctoral seminars. As a result, I chose to write this thesis using the scientific plural. The presented work is partly based on scientific papers which evolved through collaborating with colleagues and students. I refer to these publications in the introductory part of the respective chapters.

ACKNOWLEDGEMENTS

During my time as a PhD student, I had the privilege of meeting and collaborating with quite a few distinguished people. I would like to thank them for their contribution to my research which finally resulted in this thesis–not only for their professional input but also for their personal support, which made my PhD time and research so valuable. These acknowledgments are dedicated to all those excellent colleagues and friends I had the honor to work with. I sincerely apologize to everyone I might have missed to mention.

My biggest gratitude goes to my supervisor **Albrecht Schmidt** who deeply inspired and infected me with his passion for research and collaboration. I am grateful for his continuous support from my decision to start as a researcher and PhD student in his group until submitting and defending my dissertation. Influenced by his never-ending flow of ideas, he shaped the foundations of my work. Thank you, Albrecht, for your perpetual support and guidance, your fruitful and valuable discussions, for all the opportunities that you made possible during my PhD, and for your great trust. My thanks also go to the co-examiners and committee members **Andrew L. Kun**, **Manfred Tscheligi**, **Stefan Wagner**, and **Sebastian Padó**. Thank you for your feedback, comments, time, and effort!

Being part of Albrecht's outstanding work groups in Essen and Stuttgart, I had the pleasure to work with a number of excellent colleagues and friends. I am thankful to **Stefan Eicker** who directed my attention to Albrecht's group at the University of Duisburg-Essen and without whom I might not have found the group at all. Sharing an office with another person often influences our work and life. I am grateful to my office mates **Elba del Carmen Valderrama Bahamóndez**, **Stefan Schneegaß**, and **Mauro Avila**, who were not only colleagues but also became good friends. In particular, I would like to thank Stefan for his collaboration in the research projects we carried out together, for the soccer events (sharing the same passion for a particular team!) and BBQ evenings, and for the joint commutes between Herdecke, Mülheim and Stuttgart. Thanks to Elba and Mauro, I did not fully forget how to speak Spanish. I am very grateful to **Florian Alt** for his collaboration and deep friendship – and his invaluable knowledge and experience about the best road trips and sightseeing tours at almost any (conference) place in the world. Thanks also to **Alireza Sahami Shirazi** (for introducing the latest gadgets, hunting for the best – swabian! – deals), **Dagmar Kern** (especially for bringing my attention to AutomotiveUI), **Nora Broy** (for being sparring partner in the automotive domain), **Niels Henze**, **Tanja Döring**, **Tilman Dingler**, **Markus Funk**, **Miriam Greis**, **Yomna Abdelrahman** (for her awesome meals), **Mariam Hassib**, **Pascal Knierim** (for awesome alpine trips), **Thomas Kubitza**, **Michael**

Raschke, **Michael Sprenger** (for teaching the Swabian language), **Lars Lischke**, and **Sven Mayer** (for organizing excellent BBQs). Special thanks also go to **Nicole Recksing**, **Murielle Naud-Barthelmeß**, and in particular to **Anja Mebus** for always having an open door and especially protecting us from all kinds of administrative issues. I am very grateful to the students who did exciting courses, projects, bachelor, master, and diploma theses around the scope of this thesis. Special thanks go to **Michael Kienast**, **Frederik Heinrich**, **Thorsten Berberich**, and **Fabian Schulte**.

In the course of my PhD time, I also met a lot of researchers outside of my home institutions and had the privilege to work with them. I am thankful to **Manfred Tscheligi**, **Alexander Meschtscherjakov**, **Andrew L. Kun**, **Andreas Riener**, and **Ignacio Alvarez** for their collaboration on various AutomotiveUI topics and workshops. Further thanks go to **Enrico Rukzio** and **Chris Kray** for their collaborations and feedback. I thank **Andreas Butz** for the opportunity to start in his group already before this thesis was finalized.

Last, but certainly not least, I owe my greatest gratitude to my family. I want to thank my parents, **Erika Pfleging** and **Ralf Pfleging**, for their unquestioning and continuous support, love, and belief in me. Thanks to my father, I got attracted to technology and computer science quite early, and thanks to my mother I understood that education can be a lot of fun – both being an instructor and a student. What I learned from my grandmother, **Marianne Brembt**, is the passion for the Alps and to enjoy traveling (but also around the globe!). Without their help, patience, and support this thesis would not have been possible. Thank you so much!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Acronyms

AAA	American Automobile Association (p. 33)
AAM	Alliance of Automobile Manufacturers (p. 46)
ABS	anti-lock breaking system (p. 21)
ACC	adaptive cruise control (p. 21)
ADAS	advanced driving assistance system (p. 4)
AOI	area of interest (p. 52)
BASt	Bundesanstalt für Straßenwesen, German Federal Highway Research Institute (p. 38)
BPM	beats per minute (p. 101)
BTemp	body temperature (p. 110)
CDS	Crashworthiness Data System (p. 34)
CID	central information display (p. 188)
DALI	Driver Activity Load Index (p. 57)
DIN	Deutsches Institut für Normung, German standardization organisation (p. 8)
DRA	driving-related activity (p. 31)
DRT	Detection-Response Task (p. 51)
ECG	electrocardiography, *also:* electrocardiogram (graph of an ECG recording) (p. 90)
ECU	electronic control unit (p. 21)
EEG	electroencephalography (p. 90)
ESC	electronic stability control (p. 21)
ESoP	European Statement of Principles (p. 46)
FOT	Field Operational Test (p. 72)
GPS	Global Positioning System (p. 104)
GSM	Global System for Mobile Communications (p. 20)
HR	heart rate (p. 96)
HRV	heart rate variability (p. 101)
HUD	head-up display (p. 26)
ISO	International Organisation for Standardization (p. 8)
IVIS	in-vehicle infotainment system (p. 4)
JAMA	Japan Automobile Manufacturers Association (p. 46)
KLM	Keystroke-Level Model (p. 62)
LCT	Lane Change Test (p. 67)
mdev	mean deviation between path trajectory and actual driven path, measurement output of the Lane Change Test (p. 149)
NASA-TLX	NASA Taskload Index (p. 56)

NDRA	non-driving-related activity (p. 5)
NDS	naturalistic driving study (p. 44)
NHTSA	National Highway Traffic Safety Organization (p. 34)
OEM	original equipment manufacturer (p. 46)
PDT	Peripheral Detection Task (p. 51)
PND	personal navigation device (p. 21)
RTLX	Raw TLX, simplified version of the NASA Taskload Index (NASA-TLX) (p. 57)
SAE	SAE International, *formerly* Society of Automotive Engineers (p. 25)
SCR	skin conductance response (p. 96)
SDLP	Standard Deviation of Lane Position, lane position variability (p. 54)
SHRP2	Strategic Highway Research Program Two (p. 45)
SUS	System Usability Scale (p. 56)
TCT	task completion time (p. 53)
TDT	Tactile Detection Task (p. 60)
TICS	traffic and information control system (p. 32)
TLZ	traffic light zone (p. 198)
TOR	take-over request (p. 41)
TTI	time to intervention (p. 188)
TTT	total task time, *see also* task completion time (TCT) (p. 53)
UI	user interface (p. 8)
UX	user experience (p. 5)

I

Introduction & Motivation

Chapter 1

Introduction

1.1 Motivation and Timeliness

This chapter is partly based on the following publication:

- Bastian Pfleging and Albrecht Schmidt (2015). (Non-) Driving-Related Activities in the Car: Defining Driver Activities for Manual and Automated Driving. In: *Workshop on Experiencing Autonomous Vehicles: Crossing the Boundaries between a Drive and a Ride at CHI '15*. (Seoul, South Korea)

When the first cars were invented and built at the end of the 19th century (Benz And Co. 1886), their only utility was to bring passengers from one location to another. As a successor of (horse-drawn) carriages, these early cars mainly consisted of mechanical parts that were needed to offer seats to the passengers, to control the engine, and to maneuver the vehicle.

With the proliferation of cars during the 20th century more and more equipment was integrated into the car: The initially open auto body was soon designed as a closed body to protect the passengers from rain and dust and offered space to store luggage and other personal belongings. Gradually, auto makers increased the driving comfort (e.g., seats, roof, and windows) as well as the utility and safety of the vehicles. Also, technical components found their way into the car. For instance, turn signals simplified communication with other drivers while windshield wipers and headlights facilitated driving during rainy days or at night. More and more electric (and later electronic) components were integrated for the reasons mentioned before and often replaced their mechanical predecessors.

Today, driving a modern car is much more than just sitting in a vehicle to get to a distant location. Being entertained during the ride is one important aspect. Already in the 1920s first radios had been integrated into a Ford Model T[1]. Until 1953, already 40 % of the cars in Germany were equipped with a radio[2]. Despite already an early discussion that already windshield wipers might distract the driver (see for instance Curry 2001), entertainment started to become more important to driver and passengers. Of course, this was only the beginning regarding the entertainment of driver and passengers.

Similarly, with the advances of mobile communication technology, also mobile communication found its way into the car. With mobile and smart phones becoming the ubiquitous companion for the majority of people today, we see a strong need not only for entertainment but also for communication while driving a car. Many people feel that the need to be connected to the world outside of the car even while driving - for instance by using voice communication, text messages, or e-mails (Árnason et al. 2014; Sohn et al. 2008). Therefore, drivers and passengers either use their nomadic devices that they brought into the car (e.g., smart phones and tablets) or they use the functions integrated into the in-vehicle infotainment system (IVIS). Many of the advanced infotainment offer communication features that are specially designed for the automotive use case. For instance, sharing information to Twitter or Facebook with such in-car infotainment systems makes use of available context information such as time to destination or outside temperature. By also restricting the choice of options (e.g., send only pre-defined messages instead of free text entry), the complexity of such interaction shall be kept low.

Considering the latest generation of cars and those currently under development, more advanced driving assistance system (ADAS) are integrated into the car. We see a clear transition towards highly or fully automated driving modes (Gasser et al. 2012) where the driver needs to pay only little or no attention to the road situation anymore. With these assisted and automated driving modes, we expect an increased desire of the driver for non-driving-related activities such as (visual) entertainment like reading news, watching a movie, or preparing the business day.

---

1 http://www.gfu.de/home/historie/autoradio.xhtml, last access: 2014-10-15

2 http://www.carhistory4u.com/the-last-100-years/parts-of-the-car/car-radio, last access: 2015-10-20

For the near future, we expect a typical car ride to still consist of different levels of automation. In order to not compromise driving safety or limit the driver's capabilities, concepts for interaction with in-car technologies need to be designed so that they support the right activities for each level of automation.

Today the driving task (i.e., driving the car manually) has still the highest priority. Even with increasing assistance, the driver still is responsible for driving the car unless it is driving in a highly or fully automated mode (ibid.). Nevertheless, already today drivers perform many non-driving-related activities while driving and we see a need for even more tasks and entertainment in the car. At the same time, we see that many of these tasks actually distract the driver from the driving task. Thus, an important question is how such non-driving-related activities can *safely* be supported or adapted to the car. These are important issues to solve–both for manual driving situations as well as for the transition towards automated driving where we expect non-driving-related activities (NDRAs) to become even more important. Besides safety aspects, we believe that the availability and usability of such NDRAs will become a key point for customers when it comes to the decision of which car to buy or use. In this thesis, we will contemplate the different facets of NDRAs. We will have a look at different aspects that need to be taken care of when designing NDRAs for future vehicles while also considering issues such as usability and driving safety.

1.2 Research Questions

With the proliferation of smartphones and tablets that are nowadays in use everywhere and at any time, we observe the trends of (1) users being connected any time and (2) users having information and entertainment at their fingertips all day long. This demand also applies to situations where people drive their car–and with increased driving assistance, even more activities will be demanded by the drivers. To ensure and increase driving safety as well as usability and user experience (UX), it thus needs to be understood how to enable important and interesting non-driving-related activities for the car in a least distracting way. In this thesis, we will have a look at non-driving-related activities from two perspectives (see Table 1.1): From a technological perspective (discussed in Part III), we look at different aspects that are necessary to enable an integration of NDRAs into the car. From the driver's perspective (see Part IV), we also show concepts of how to integrate actual activities into the car.

As non-driving-related activities become more important, it is important to understand the different requirements and regulations for such tasks (R1). To enable NDRAs in the car, many aspects need to be taken into account that ensure a safe and usable interaction between driver and car. Thus, on the one hand legal requirements need to be taken into account as well usability and user experience aspects. Additionally, for the case of manual driving situations it is important to know details about the current driving situation to enable a situation-based support for NDRAs.

One important detail for manual driving scenarios as well as for handover situations between driver and car/assistance systems is the driver's state, i.e., his current activity and mental workload (R2). In situations where the workload is high, probably certain activities should be halted or simplified. For instance, it might be acceptable to support communication when driving on a straight highway with only little traffic but not while entering an extremely crowded highway. One idea is here, to use measurements of the driver's workload to adapt the car interfaces and tasks to the current situation.

As the variety of available functions and activities grows with each new generation of cars, it is no longer possible to control each function by separate controls such as knobs and buttons (Kern and Pfleging 2013). Thus, new concepts need to be found that enable the driver to easily access all available functions of the car (R3). Besides access to functions in general, it is also important to provide interaction capabilities that the drivers enjoy to use. Especially stimulated by the usage of consumer devices (e.g., smartphones and tables), drivers today expect certain interaction styles. Since a manual drive still requires a permanent visual monitoring of the environment, systems should provide alternative, multimodal interaction concepts that offer different input and output modalities. With this regard, we have a look at an approach that aims to facilitate speech interaction and combine it with touch interaction on the steering wheel.

Considering the NDRA themselves, it is interesting to investigate which tasks drivers want to use on the go. One important task is communication–either through an audio connection (i.e., a phone call) or via text messages (SMS, instant messengers, e-mails). As shown in literature communication while driving increases the risk of having an accident (Caird, Willness, et al. 2008). However, since statistics show that drivers use mobile phones even though some used is prohibited, we assume that communication cannot be banned completely while driving. Therefore, it is of interest how communication means can be modified to increase driving safety and responsibility (R4). For instance, sharing context information with a remote party would allow people outside of the car to defer phone calls to a later time. Similarly, using a live video of the road situation

Table 1.1: Summary of research questions.

Research Question	No.	Chapter
I. Supporting Non-Driving-Related Activities		
What is required to support non-driving-related activities in the car?	(R1)	Chapter 3
How can the driver's mental workload be assessed and employed?	(R2)	Chapter 4
How can (multimodal) interaction be improved for in-vehicle interaction for an easy access to a multitude of functions? How can we overcome limitations of unimodal approaches?	(R3)	Chapter 5
II. Examples for Non-Driving-Related Activities		
How can we adapt car-mediated communication to increase driving safety and responsibility?	(R4)	Chapter 6
How can we enable time-adjusted media and tasks?	(R5)	Chapter 7

would allow phone callers to behave like a virtual passenger who is able to react to special driving condition (e.g., be quiet during difficult situations or even warn the driver). We propose a concept to address these issues and investigate the user's needs and attitudes for context-enriched communication.

Especially for automated driving situations–but also when the (manually driven) car is standing still–the driver wants to do other tasks such as watching media, reading the news, or other tasks. One can image many driving situations that might only last for a certain time. For instance, the highway driving assistant might only be able to drive (highly) automated until the next exit in 3 minutes or it will take 45 seconds until the traffic light permits driving again. Having this knowledge about timings when the driver needs to redirect the attention back to the road, one might want to think about concepts that allow the execution of time-adjusted tasks or the consumption of time-adjusted media contents. Thus, the question is how to enable such time-adjusted activities (R5). With this regard, we present a concept for such time-adjusted NDRAs, which we evaluated through an online survey and a case study.

1.3 Methodology

Being an interactive computing environment that is moving around on the road, the car is a very specific domain for human-computer interaction. On the one hand, the specific requirements for maneuvering a vehicle need to be taken into account, on the other hand, methods known from human-computer interaction as know for instance from desktop environments or mobile devices, should be considered as well. A well-known human-centered design process for computer-based interactive systems is defined as the standard DIN EN ISO 9241-210:201 (DIN 2011a). This process is an iterative model including steps to understand the context of use, specifying user requirements, up to designing and prototyping solutions before they are evaluated. These steps are repeated until a solution has been found that is satisfactory to the user. Regarding the user interface, this process can also be applied to the car.

The various aspects of non-driving-related activities relate to different parts of the DIN EN ISO 9421:2010 design process. Thus, different approaches and methods were used to investigate each single aspect. In a bottom-up approach, these aspects have been investigated throughout the last years in various small to medium-sized projects conducted in close collaboration with colleagues, other researchers, student workers and undergraduates, which considered separate aspects each. With these findings, we hope to contribute to the design of future non-driving-related activities in the car.

The methods employed to extract the core findings presented in this thesis relate to different parts of the human-centered design process. For instance, web surveys were used to gather early user opinions and expectations from drivers. Similarly, prototypes have been designed and developed that take into account the special requirements and context of the car. These prototypes were evaluated, for instance using a driving simulation environment or even a real-world driving study.

1.4 Research Contribution Summary

This thesis contributes to the field of automotive user interfaces with a special focus on non-driving-related activities. As a first contribution, we provide design guidelines which facilitate the development of such automotive user interfaces (UIs) that enable performing NDRAs in the car. These guidelines take prior work into account but add a special focus on the driver's needs for NDRAs. Second, we take a closer look at the technical aspects that support performing NDRAs in the car. We have a close look at integrating mental workload measurements as an implicit way to understand the driver's state. The idea is to use this information as in input for in-vehicle systems in order to be able to react to overload and underload. Also, this is helpful for future automated vehicles where this information can be used to decide whether the level of driving automation needs to be adjusted to the driver's current activity. In addition, we explore a novel multimodal interaction style for the car in order to facilitate interaction with many features and to overcome challenges of existing unimodal interfaces. Third, we explore the space of NDRAs. Exemplary, we look at car-mediated communication in the car with the goal to improve driving safety while retaining the driver's opportunities. With regard to entertainment and productivity (e.g., reading e-mail) we have a look into specific situations where it is known that the driver's attention is (almost) not required for a certain period. For these situations, we present a concept of time-adjusted tasks that allow the driver to perform NDRAs which terminate just before his or her attention is required again for the driving situation.

Summarized, we present concepts and findings that

- support the design and development process of non-driving-related activities in the car
- offer a multimodal approach to interact with (non-driving-related) functions and objects in the car
- aim at increasing driving safety during communication between the driver and the outside world
- provide a framework to infer information about the driver's state to allow for a better context-based support for interaction or even hand-over situations between car and driver
- support time-adjusted NDRAs for situations where the driver is able to dedicate his or her attention to tasks beyond driving.

1.5 Overview and Outline

The body of thesis comprises five parts separated into eight chapters in total. Next to this *Introduction & Motivation* part the *Background* part presents an in-depth introduction to automotive user interfaces. It is followed by the two main parts of this thesis. First, the part on *Designing the User Interface* offers support for designers and developers on how to develop and design automotive user interfaces that support non-driving-related activities. This part also contains a chapter on using workload as one input detail for novel automotive user interfaces and another chapter that presents a new multimodal interaction style for the car. Second, the part on *Non-Driving-Related Activities* outlines two concepts to support and introduce non-driving-related activities in the domain of communication and entertainment. The thesis closes with a part comprising *Conclusion and Future Work* where the research contributions are summarized and discussed. This includes also an outlook towards future work. Overall related work is discussed as part of Chapter 2 (Background and Related Work). Related work regarding specific aspects of subsequent chapters is also integrated into the particular chapter.

Part II: Background

Chapter 2–Background and Related Work: In this chapter, automotive user interfaces are introduced in depth, especially regarding driving activities or driving tasks, driving context, and the design of novel interfaces. The chapter starts with a retrospective which looks at the evolution of cars and automotive user interfaces. For a common understanding the following section introduces important terms related to automotive user interfaces and the tasks and activities while driving. After this, a section on statistics and car accidents outlines current efforts to analyze traffic accidents as a basis for future research to minimize such accidents. With this regard, existing statistics are presented as well as novel approaches such as naturalistic driving studies that aim for a better understanding of reasons why certain accidents happen. These statistics show that driving a car can be a dangerous activity, for instance when performing additional tasks while driving. In order to ensure driving safety, to unify certain behavior and interface use, and to facilitate interaction with the car, a variety of standards and guidelines have been developed. The following section takes a closer look at those guidelines and standards that are related to the design and use of automotive user interfaces. In order to comply with these standards, most interfaces need to be evaluated multiple times throughout the design and development process as well as when performing research on novel interfaces. Thus, the remainder of this chapter discusses the different possibilities to evaluate automotive user interfaces.

Part III: Designing the User Interface

Chapter 3–Supporting Non-Driving-Related Activities: With the trend of ubiquitous and pervasive computing we see an increasing need of current drivers to perform additional tasks (i.e., non-driving-related activities such as texting, calling, or other forms of entertainment) while in the vehicle. Depending on the driving situation, these activities may pose the driver and the current surrounding at risk by causing traffic accidents. As a consequence, automotive user interfaces that aim to support such activities need to be carefully designed in order to allow safe driving but also permit performing such activities. To support the challenge of designing such user interfaces, this chapter provides a framework for the design of future interfaces. In detail, we first present guidelines that take the special need for non-driving-related activities into account. These guidelines are heavily based on related work and existing guidelines and standards. They are completed with our own experiences and impression of the past years. In contrast to previous work, we aim to focus more on the user and on allowing non-driving-related activities. Furthermore, we provide an exemplary context-supported model to support the development of multimodal automotive user interfaces. Finally, we outline and categorize different types of content information that can be helpful for the design of context-aware user interfaces and multimodal interaction in the car. Since the contribution of the whole thesis is to support the different aspects of designing non-driving-related activities in the car, this section also reflects the experiences of the research conducted during the last years and which are part of the subsequent chapters. Thus, the chapter concludes with a section that outlines the relation of the guidelines and model presented in this chapter to the remaining chapters that consider certain aspects of non-driving-related activities.

Chapter 4–Investigating the Driver's Workload: In this chapter, we explore how to infer additional details about the driver's state and workload. This is beneficial for automotive user interface in order to especially prevent situations of driver overload as well as for automated driving. Nowadays, most interfaces do not distinguish between different driving situations other than standing still or driving. Thus, when supporting non-driving-related activities while driving, situations may appear where already the driving context poses a high workload on the driver. If an additional unadapted NDRA is performed in such a situation, this may lead to driver overload and degradation in driver performance. It is, thus, of interest to know how the driver's workload is like in different driving situations (e.g., on a highway compared to a residential area) as well as to retrieve such details in real time to allow interfaces to adapt their functionality and appearance in accordance with the current driving situation and workload. Similarly, in future vehicles that are able to drive highly automated for parts of the ride and need to hand over control back to the driver at some point, such measurements are important as well. They provide hints to the vehicle whether the driver is alert and able to take over control or what needs to be done to prepare him/her for the take-over situation. To tackle these issues, we first discuss the definition of workload in this chapter and outline different methods how to measure certain aspects of workload. Since we were interested in understanding the drivers' behavior and workload on the road, we then report on a case study where we equipped ten drivers with physiological sensors to infer workload measurements on the go. Using a post-hoc video analysis, we gathered additional subjective feedback which allowed us to correlate subjective and physiological data. The data set–which is also available to the public–should help future developers to create workload-adaptive user interfaces.

Chapter 5–Facilitating Enjoyable Multimodal Input: Compared to the very first cars, modern cars have a much larger set of functions and features that want to be controlled while driving. This relates both to driving- and non-driving-related activities. Having more than 700 functions in modern vehicles (Zeller, Wagner, and Spreng 2001), it is no longer possible to use a physical button for each function or feature. Thus, current approaches often employ hierarchical menus that are controlled on a touch screen or using a display and a central controller. Since speech-only interaction has not taken off yet, in this chapter we propose a novel approach that combines speech interaction and touch gestures which can be performed on the steering wheel. Next, we present a prototype that implements this interaction style to operate non-driving-related functions and report on a study where we compared this approach to a traditional interface. In consideration of automated driving situations, we also outline how this approach can be useful to enable enticing non-driving-related activities through a novel interaction style.

Part IV: Non-Driving-Related Activities

Chapter 6–Context-Enriched Communication: Using the mobile phone to communicate with the outside world is an NDRA that is frequently performed in the car. As documented through a variety of analyses by other researchers, we know that calling or texting while driving increases the risk of being involved in an accident. Laws that try to restrict such communication in the car did not change much with this regard: They are often neglected by many drivers and most laws only forbid handheld calling even though the conversation itself is the most distracting fact. Thus, it is of interest to find alternatives that support communication as a non-driving-related activity but which limit the additional risk at the same time. One approach with this regard is to create an awareness of (the risk) of the driving situation in order to initiate a behavior change with regard to communication. As one example, we propose in this chapter a concept where abstract information and/or a video of the driving context is shared with the remote party. The idea is that this helps to increase driving safety by reducing the amount of communication. For instance, calls to ask for the estimated arrival time or the current location would become obsolete since this information can be available to the remote party before or during setting up a phone call. Another option for a remote party could be to postpone the call until the car is stopped or until the driver has switched to a higher level of automation. Using a live video instead might increase the remote party's awareness of the driving situation by feeling like a virtual passenger. To investigate this concept, we conducted a web survey to analyze multiple aspects. First, we identified the current communication behavior in the car. Second, we explored how and which context information drivers or callers would like to share or know before or during a phone call. To complement these insights, we conducted in-depth interviews to understand the driver's and callers sharing attitudes and needs. Based on these findings, we propose guidelines for the design of car-mediated communication functions in cars.

Chapter 7–Time-Adjusted Media and Tasks: Entertainment, relaxation, and office work are examples of NDRAs that are of special interest to current drivers. At the moment, for most driving situations only audio entertainment (e.g., listening to songs or the radio) are recommended since the driver's visual attention should be directed to the road. However, already today (for instance while waiting at a traffic light) but especially when driving automated in the future, we see situations where the screens that are already installed in the car could also be used for visual entertainment and NDRAs– at least for a certain time span. As a consequence, in this chapter we present a concept for enabling time-adjusted (visual) NDRAs in the car. We present the findings of an online survey on the potential of micro-entertainment and time-adjusted NDRA. Furthermore, we report on an exemplary case study where we applied this concept to the waiting times and zones in front of traffic lights and report on the qualitative findings of this experiment.

Part V: Conclusion and Future Work

Chapter 8–Conclusion and Future Work: In this chapter, we summarize and discuss the findings presented in this thesis. Also, we identify and discuss potential projects for future work.

II

Background

Chapter 2

Background and Related Work

In this thesis, we explore how to support non-driving-related activities while driving a car. To understand the challenges of performing tasks that are not directly related to driving, it is important to know the fundamentals of the driving context and the design of automotive user interfaces. This chapter provides an overview of the driving context and essential facts related to the development of automotive user interfaces.

First, we provide a concise overview on important milestones of the development of cars and look at the overall research landscape of automotive user interfaces. As a next step, important terms in the domain of automotive user interfaces that are used throughout the thesis will be explained. Since driving a car is an activity that can be dangerous for drivers, passengers, and the environment, many standards and guidelines have been developed to provide hints on how to design and develop state-of-the-art vehicles. This holds as well for the specific sub-task of designing the automotive user interface. Thus, the most important guidelines and standards will be explained in this chapter as well. It is important to keep these guidelines and standards in mind during the development of new automotive user interfaces. In order to comply with these guidelines, most interfaces will be evaluated at least once during the development phase. The last part of this chapter gives an overview of typical evaluation methods for automotive user interfaces. This also shows how these evaluation methods differ from evaluating traditional (e.g., desktop) user interfaces and which additional metrics are taken into account.

This chapter is partly based on the following publications:

- Bastian Pfleging and Albrecht Schmidt (2015). (Non-) Driving-Related Activities in the Car: Defining Driver Activities for Manual and Automated Driving. In: *Workshop on Experiencing Autonomous Vehicles: Crossing the Boundaries between a Drive and a Ride at CHI '15*. (Seoul, South Korea)
- Nora Broy, Florian Alt, Stefan Schneegass, and Bastian Pfleging (2014). 3D Displays in Cars: Exploring the User Performance for a Stereoscopic Instrument Cluster. In: *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '14. Seattle, WA, USA). ACM: Seattle, WA, USA, 2:1–2:9. ISBN: 978-1-4503-3212-5. DOI: 10.1145/2667317.2667319
- Stefan Schneegass, Bastian Pfleging, Nora Broy, Frederik Heinrich, and Albrecht Schmidt (2013). A Data Set of Real World Driving to Assess Driver Workload. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 150–157. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516561
- Stefan Schneegass, Bastian Pfleging, Dagmar Kern, and Albrecht Schmidt (2011). Support for Modeling Interaction with Automotive User Interfaces. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 71–78. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381428

2.1 History: Cars as Mode of Transportation

Being mobile is a desire and need of human beings ever since. The invention of the wheel more than 5500 years ago was a major step when it comes to moving objects or even carry people from one place to another. Riding some kind of (horse-drawn) carriage soon became a rather comfortable mode of transportation–at least for those people that actually had the privilege to use such a carriage.

Experiments with vehicles that do not need to be drawn by horses or need to be moved using one's own muscles (e.g., bicycles) started soon after the invention of the steam machine. Ultimately, this lead to the invention of first steam trains being available in England and Germany from the first half of the 19th century. However, for individual mobility with small vehicles, first prototypes implementing vehicles with combustion engines that we can consider as ancestors of today's cars, came up during the late 19th century. One prominent example, often cited as the first car, is the prototype developed and 1886 patented by Carl Benz (Benz And Co. 1886) which had its first long-distance ride in 1888[1]. With the first integration of a steering wheel into the car in 1894[2], most of the primary controls had been introduced that one can still find in the car today.

A breakthrough of the automobile was clearly the start of mass production of cars such as with the Ford Model T in 1913[3]. Regarding interaction in the car and interactivity, the introduction of the car radio in the 1920s was the next bigger invention, even though it took roughly until the 1950s / 1960s until car radios were established as a standard add-on. Later, these radios also included the possibility to playback tapes and digital media such as compact disks (CDs) and thus increased the driver's choice for personal entertainment and flexibility. With the advance of digital media in home, desktop, and mobile environments, also the capabilities of the car radio were extended such that today it is also possible to play back music files (e.g. MP3 files) from different sources such as integrated hard disks (often found in expensive in-vehicle information systems), USB sticks, memory cards, or remotely from mobile devices over Bluetooth (wireless) or USB (wired).

First attempts of being available by two-way radio or phone even in the car were already made in the 1940s. For instance, Motorola installed "the first

1 http://www.daimler.com/dccom/0-5-1322446-49-1323352-1-0-0-1322455-0-0-135-0-0-0-0-0-0-0-0.html, last access: 2015-02-20

2 http://www.autoevolution.com/news/history-of-the-steering-wheel-20109.html, last access: 2015-05-01

3 http://www.ford.co.uk/experience-ford/Heritage/EvolutionOfMassProduction, last access: 2015-05-01

commercial FM two-way taxi communications system" in Ohio in 1946[4]. Two years later, 1946, Motorola and Illinois Bell Telephone Company initiated a "car radiotelephone service" in Chicago[4]. In Germany, the first documented integration of a carphone into a taxi dates back to 1952 (price: about 15,000 DM), but it took until 1958 to start the first extensive mobile network ("A-Netz")[5]. In the following decades, the development of carphone systems continued towards devices with increased functionality and reduced size and weight[6].

As the initial costs for carphones and their integration into the car were quite high, only a limited group of privileged users (e.g., business owners, politicians, etc.) were able to afford such a device. With the introduction of digital mobile telecommunication standards such as Global System for Mobile Communications (GSM) in the 1990s[7], it soon became the norm to own and use a mobile phone. Thus, the number of subscribers grew rapidly from 11 million users in 1990 to 738 million by the end of 2000[8]. The trend of being available anywhere at any time did not stop outside of the car: Soon drivers were using their mobile phones even when driving in the car. It did not take long until accident statistics showed that calling and texting while driving impacted the drivers as they were distracted by their mobile phones. Thus, in many countries, legislation banned handheld calling and allowed for handsfree calling only. To enable handsfree communication in the car, wired or wireless connections (e.g., through Bluetooth) provide a link between the mobile phone and the entertainment or (even portable) navigation system. The latter provide speakers, microphones, and controls such as buttons to operate the phone without holding it in one's hand.

The mock-up of the plan-position-indicator screen[9] in a James Bond movie in 1964 ('Goldfinger') is one of the earliest proofs for the concept of (satellite-based) navigation systems. However, it took almost 20 more years until the first commercial satellite navigation system became available between the 1980s and

---

4 http://www.motorolasolutions.com/US-EN/About/Company+Overview/History/Timeline , last access 2014-11-10

5 http://www.wissen.de/die-geschichte-der-mobiltelefone, last access: 2015-02-04

6 http://smartphones.wonderhowto.com/inspiration/from-backpack-transceiver-smartphone-visual-history-mobile-phone-0127134/, Last access: 2015-02-03

7 http://www.gsma.com/aboutus/history, last access: 2015-01-20

8 International Telecommunication Union (ITU): Global ICT developments, derived from time series by country, http://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2012/Mobile_cellular_2000-2011.xls, last access 2015-05-10

9 http://www.ieeeghn.org/wiki/index.php/Technology_in_the_James_Bond_Universe, last access: 2014-11-10

1990s (Akamatsu, Green, and Bengler 2013). While it is not clear which company sold the first usable system[10], there is no doubt that this was the time when the first digital maps became available in cars as well as it was possible to find the car's current location on such a map. Soon, also personal navigation devices (PNDs) could be purchased. Today, car navigation is either realized through full-fledged in-vehicle "infotainment" systems (IVIS) that offer *info*rmation (e.g., navigation, traffic jams, weather forecast), enter*tainment* (e.g., radio, CD, MP3, videos), and communication capabilities (e.g., calling, texting, e-mail, and Internet).

With a massively increasing number of cars after the Second World War, soon also the number of–often severe–accidents rose. This posed the demand for increased driving safety, leading to inventions such as the seat belt which was first marketed by Volvo, Ford, and Chrysler in 1956 (The Royal Society for the Prevention of Accidents n.d.). Similarly, the crumple zones and the safety passenger cell were invented between 1951 and 1952 at Mercedes Benz[11] (Akamatsu, Green, and Bengler 2013). The airbag was already invented in 1951 (Linderer 1951) but only sold from 1973 on in first General Motor cars[12]. While many of the first safety inventions were of mechanical nature, the airbag and later systems like anti-lock breaking system (ABS) that was marketed since 1971[13]) and electronic stability control (ESC)–marketed since 1995 (Nicholson 2007)–were the first systems that were controlled by sensors and electronic control unit (ECU). Throughout the last 25 years, we see an increasing number of such control units for various purposes.

In modern cars, the electric control units often assist the driver regarding certain driving tasks, for instance regarding lane keeping, maintaining speed and distance to the lead vehicle through adaptive cruise control (ACC), or monitoring the blind spot. Such systems are nowadays called advanced driving assistance systems (ADASs). When combining all assistance systems available today, from a technical point of view, many of the tasks a driver needs to execute when driving a vehicle, can already be managed by the car itself. While typical usage situations can be managed (e.g., driving on a highway, parking) by the car, this is not yet

---

[10] see for instance http://en.wikipedia.org/wiki/Automotive_navigation_system, last access 2014-11-11

[11] http://www.daimler.com/dccom/0-5-1301673-1-1281369-1-0-0-1301966-0-0-135-0-0-0-0-0-0-0-0.html, last access: 2015-01-20

[12] http://inventors.about.com/od/astartinventions/a/air_bags.htm, last access: 2015-06-28

[13] http://www.hagerty.com/articles-videos/Articles/2013/04/09/Antilock-Brakes, last access: 2015-06-28

possible for exceptions such as construction sites or certain weather conditions[14]. Also, as defined in the Vienna Convention on Road Traffic (published as a German law in BGBl. Teil II 1977) from a legal perspective, highly automated driving with a driver not paying permanent attention to road, car, and environment is not yet permitted in general (Schöttle 2014). However, first vehicle prototypes have already shown the feasibility of automated driving. These range from cars that are equipped with a large portion of additional technology and sensors (e.g., the cars by Google) to cars that mostly rely on technology which has already been integrated in production vehicles. For the latter, Mercedes showed the feasibility in a close-to-production vehicle on their first drive in the tracks of Bertha Benz[15]. The technological advances cause laws to be updated laws to address the novel requirements of automated cars.

2.2 Interfaces for Driving a Car

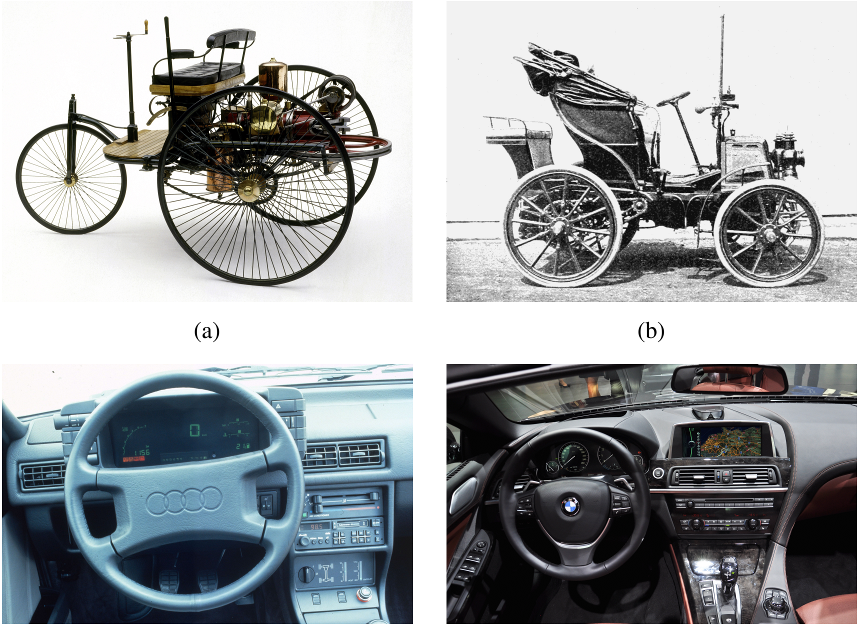
The way the driver interacts with and controls the car has changed throughout the history of the car. In this section, we outline the major influences and changes in the past and present and provide an outlook on future automotive interfaces. Research in human-computer interaction in the automotive context has grown in the last years. Finding enabling interaction that is at the same time pleasant and minimally distracting is a common goal. A major challenge is to combine means for interaction for the different tasks when driving a vehicle. With advances regarding automated driving there may be new possibilities for the driver to perform activities that are not directly related to maneuvering the vehicle. It will be interesting to see how this influences the interaction concepts for automotive user interfaces.

2.2.1 History of Automotive User Interfaces

The first cars built at the end of the 19th century were controlled in a different way then the cars we drive today. The inventors borrowed some of their interaction con-

[14] http://www.motor-talk.de/news/bei-diesem-auto-ist-langeweile-das-ziel-t4941424.html, last access: 2015-10-20

[15] http://media.daimler.com/dcmedia/0-921-614307-1-1629819-1-0-1-1630016-0-1-0-1549054-0-1-0-0-0-0-0.html?TS=1422988532448, last access: 2015-01-20



(a) (b)

(c) (d)

Figure 2.1: Historic development of the automotive UI from the first motor vehicle until today's production vehicles.
(a) Carl Benz's Patent-Motorwagen #1 used a tiller for steering.
(b) A Panhard and Levassor vehicle from 1900 shows an early example of a steering wheel integrated into the car.
(c) In the 1970s, Audi introduced one of the first car cockpits with a digital dashboard in their quattro cars.
(d) The BMW 650i xDrive Cabrio cockpit exemplary represents a modern high-end production vehicle cockpit.
Image sources: (a) ©Daimler AG, used with permission, (b) Public domain, via Wikimedia Commons[a], originally published in Popular Science Monthly Volume 57, (c) ©Unternehmensarchiv AUDI AG, used with permission, (d) own image.

[a] http://commons.wikimedia.org/wiki/File%3APSM_V57_D609_Panhard_and_levassor_vehicle.png, last access: 2015-05-02

cepts from other transportation domains, for instance from the nautical industry[17]. This holds for instance for the tiller respectively the crank that was first used to steer the car (ibid.) which can also be seen in Carl Benz's Patent-Motorwagen #1 as shown in Figure 2.1a. Since the tiller was soon found to be ineffective, first recorded experiments with replacing the tiller with a steering wheel (as another inspiration borrowed from ship helms) were made in a Panhard car in 1894 (ibid.). Figure 2.1b shows a similar Panhard and Levassor car from 1900. The steering wheel soon became a standard to maneuver the vehicle such as in the Mercedes 35 PS in 1900/1901 in Germany[18].

Controls to accelerate and decelerate the vehicle also changed during the early development of vehicles. Early brake systems used a hand-operated lever that was used to press a wooden block against one of the wheels to slow down the vehicle (Akamatsu, Green, and Bengler 2013; Benz And Co. 1886). In 1896, the Benz Velo debuted with a foot pedal to operate a band brake[19] which allowed to exert a greater force than the hand brake. The first Benz Motor-Patentwagen actually combined the braking functionality and the activation of the only (forward) gear in a single lever (Benz And Co. 1886): Moving the lever forward from the middle "idle" position engaged the gear. Instead, moving the lever backward first set the engine to idle, and a further movement activated the brake. The speed could be adjusted using a sleeve valve mounted underneath the driver seat[20]. Later, many vehicles were operated with a shift lever on the steering column (Akamatsu, Green, and Bengler 2013) before the gear lever was moved to the center stack as it is common today.

While the first vehicles did not carry any gauges, around the first decade of the 20th century gauges to monitor oil flow or water pressure, speedometers, thermometers, and clocks found their way into the vehicle (ibid.). They were first mounted outside of the bulkhead. Later, instrument panels gathered all gauges starting the late 1910s, but still with inconsistent arrangements (ibid.). Horn buttons in the center of the steering wheel were introduced by the end of the 1920s as well as labels to indicate the functions of switches and knobs (ibid.).

---

[17] http://www.autoevolution.com/news/history-of-the-steering-wheel-20109.html, last access: 2015-04-20

[18] http://www.daimler.com/dccom/0-5-1322446-49-1323365-1-0-0-1322455-0-0-135-0-0-0-0-0-0-0-0.html, last access: 2015-05-01

[19] https://mercedes-benz-publicarchive.com/marsPublic/de/instance/ko/Benz-Velo-Velociped-15-PS---1894---1898.xhtml?oid=4367, last access: 2015-05-01

[20] http://media.daimler.com/dcmedia/0-921-1088722-1-1241563-1-0-0-0-0-1-0-614318-0-1-0-0-0-0-0.html?TS=1431627749177,last access: 2015-04-30

To communicate left or right turns, early vehicles since the 1910s used an arm or flag that was mechanically extended from the side of the car (ibid.). To operate this indicator, a switch or lever on the steering column was added in the late 1930s. In the 1950s the indicator became an electric lamp in Germany (ibid.).

With human factors research starting around the time of the Second World War, concentrated activities began to investigate various human factors aspects, advance passenger safety, and develop national and international standards (ibid.). For instance, in 1977 SAE International (SAE) J1139 (SAE 1977) was published to standardize the direction-of-movement of in-vehicle controls to reduce confusion among drivers (Akamatsu, Green, and Bengler 2013). Similarly, symbols were introduced in the 1950s in Europe to label controls instead of using written words to avoid localization issues when cars were sold to different countries (ibid.). A standardization of such symbols for instance took place in 1974 by SAE with SAE J1048 (SAE 1974), later also within the European Communities (Commission of the European Communities 1978) and by means of a standard of the ISO (ISO 2575, latest version see ISO 2010a). Similarly, the location and distances between accelerator, service brake, and clutch were standardized in 1975 with ISO 3409:1975 (ISO 1975). While analog gauges and indicator lamps have already been used for many decades, digital displays such as speedometers were introduced in the 1970s with the Audi quattro being one of the first vehicles which included such a digital dashboard (see Figure 2.1c).

Based on the general layout of a car and of the driver's interaction area Kern and Schmidt (2009) proposed a design space for in-car user interfaces (UIs). Their design space describes the typical interaction area of the driver and also provides an overview of typical interface elements as outlined in the following two paragraphs. This design space can help to identify potential overload areas, reason about driver distraction, and help to assess trends in automotive UIs. Considering the overall input and output modalities, they also provide an overview of typical input and output modalities used in modern cars.

Common input modalities are (a) (soft) buttons that mainly communicate their status through visual feedback, (b) buttons with haptic feedback where the current status can be "felt" without looking (Kern and Pfleging 2013), (c) discrete knobs, (d) continuous knobs, (e) sliders, (f) stalk controls / levers, (g) pedals, (h) thumb wheels, (i) multifunctional knobs ("push and turn controllers" such as BMW iDrive, Mercedes Command, and Audi MMI), (j) touch screens or touch panels, (k) speech input, and (l) gesture input. Besides the last five control types, most elements were already integrate in the early years of the car.

Kern and Schmidt (2009) further outline the different output modalities such as (a) analog gauges, (b) digital gauges (e.g., speedometers), (c) virtual analog gauges, (d) indicator lamps, (e) shaped (symbolic) indicator lamps, (f) digital displays, (g) multifunctional (computer) displays, (h) auditive feedback through loudspeakers (sound and voice), and (i) vibration feedback. Figure 2.1d shows a typical driver workplace of a current high-end production car, in this case a BMW 650i xDrive Cabrio.

2.2.2 Recent Technology and Research

Head-up display (HUD) as a special type of displays that superimpose information onto the forward view were introduced in the late 1980s by Geneeral Motors and Nissan (Akamatsu, Green, and Bengler 2013). Integrated interfaces that combine the operation of multiple functions appeared in the late 1990s (ibid.), often controlled through a push-and-turn controller or a touch-enabled screen.

Touchscreens for menu interaction and text entry can be found in many cars today. Touchpads (González et al. 2007) are an alternative option. They are commonly used as remote input devices or to write text. Spies et al. (2011) investigated a haptic touchpad as a mean for controlling in-car UIs. The surface of this haptic touchpad es embossed at those locations that correspond to an interactive object (e.g., a button) that is shown on the central display. This allows facilitates interaction since the driver can feel such objects and interact with them. While finding embossed objects might be possible without looking, this approach still needs visual attention since the driver may for instance need to distinguish between different buttons by looking at the screen. Döring et al. (2011) used gestures of a multi-touch steering wheel for a gesture-based interaction style used in different applications, for instance car navigation and music player. In their work, a gesture set was created in a user-centered design process. The comparison of the gesture set with classical means for interacting with an infotainment system showed that using gestures reduces the visual demand for interaction tasks. However, the use of gestures introduces a similar problem as buttons: scalability. By using gestures that do not need visual attention, the gesture rapidly becomes complex and hard to remember. By using touch interaction that relates to the displayed content on the screen, the benefit of reduced visual attention is lost.

In order to lower workload and driver distraction, different input modalities are being evaluated. Gaze and body posture are two examples of implicit modalities that can be used to provide more natural forms of interaction that have the potential to reduce cognitive load. Gaze interaction was explored by Kern, Marshall, and

Schmidt (2010). Here, the last fixation of the user's gaze before switching attention from the screen to the road was recorded. This fixation was used to highlight the corresponding area on the screen. When the driver switches the attention back to the screen, the time to find the last gaze location can be reduced.

Voice input has been investigated for in-car interaction for years, and many efforts focus on the improvement of recognition accuracy of speech input (Winter, Grost, and Tsimhoni 2010). Speech interfaces have for instance been deployed in the Project54 system (Miller and Kun 2013). Nevertheless, voice interaction is still not widely accepted in the automotive domain (Pickering, K. Burnham, and M. Richardson 2007). Besides some remaining technical difficulties, the lack of conceptual clarity is another problem. This topic is addressed by the use of a natural voice interfaces, as discussed by Alvarez et al. (2011), however, this approach has its limitation with regard to immediate feedback and visibility of commands. The perceived UX is another crucial aspect, in particular for speech UIs. This issue was for instance investigated for in-car speech input by Goulati and Szostak (2011).

Multimodal systems are defined by Oviatt (2012, p. 405) as those systems "that process two or more combined user input modes–such as speech, pen, touch, manual gestures, gaze, and head and body movements–in a coordinated manner with multimedia system output". Multimodality can be seen as offering alternative channels (e.g., an action can be accomplished by using either of the available modalities) or as interaction using two or more modalities at the same time. Müller and Weinberg (2011) make a more sophisticated distinction of multimodality in the car and describe three methods for combining different modalities: fused modalities, temporally cascaded modalities, and redundant modalities. Such interfaces slowly enter the market as well. Jaimes and Sebe (2007) provide an extended view on multimodal human-computer interaction, especially from a computer vision point of view.

Considering the interaction possibilities and research trends, today many interaction aspects are related to additional tasks beyond maneuvering the vehicle. While many controls are still related to safety (lights, indicators, horn, etc.) or to assistance functions (lane keeping, adaptive cruise controls), a large amount of controls is used for entertainment and communication functions. We expect this trend to continue–especially with the advances of automated driving. Prototypes of highly or fully automated vehicles such as the Google self-driving vehicle[21] show one potential future of automated vehicles (see Figure 2.2a). In this car, not

[21] http://googleblog.blogspot.de/2014/05/just-press-go-designing-self-driving.html, last access: 2015-02-20

(a) (b)

Figure 2.2: Exemplary concepts for the interior of automated cars:
(a) The envisioned automated car by Google only has an emergency-off button as major interface element but no controls to manually drive the car.
(b) The prototypical Mercedes F 015 is able to drive automated but also provides a steering wheel for manual driving. Here, the configuration for automated driving is shown.
Image sources: (a) Own image, (b) ©Daimler AG, used with permission.

more than an emergency button is present to control the actual drive. Thus, a broad range of activities and interaction possibilities will arise as the driver will be able to perform all kinds of activities. This includes productivity tasks, entertainment, or potentially even sleeping–while the car is moving (highly or fully) automated. When manual driving is still necessary or desired from time to time, the Mercedes F015 shows another prototype for future vehicles. In this car, the steering wheel can be stowed away when driving automated (see Figure 2.2b). Also, the seats can be turned backwards to facilitate communication with the backseat passengers and to make use of the broad set of entertainment and information features.

2.3 Terms

To discuss issues related to the driver's workplace and tasks in the car, it is necessary to have a common understanding of the terms related to this environment. In this section, we therefore introduce the most important terms that are used throughout this thesis as well as in related work. In this thesis–without loss of generality–the terms car and vehicle relate to passenger vehicles/light vehicles unless stated otherwise.

2.3.1 Driving Task and (Non-)Driving-Related Activities

In literature the tasks and activities a driver needs or wants to perform on the go are referred to as *driving tasks* today. To distinguish different tasks, it is common to split the driving task into two (Wierwille 1993) or three (Bubb 2003; Kern and Schmidt 2009) classes:

Primary Driving Task The primary driving task comprises all activities that are required to maneuver the vehicle. This includes all activities regarding lateral and longitudinal control of the vehicle (DIN 2003b) as well as "maintaining alertness to traffic and other potential hazards" (Wierwille 1993). The primary task itself is a hierarchically cascaded task (Bubb 1993; Geiser 1985): On the highest level, the goal of the *navigation task* is the overall transportation task, i.e., getting from location A to location B. From this task, details such as route and (average) speed can be derived, which are then part of the *guidance task* on a lower level. This includes choosing the exact path as well as adapting to appropriate driving speeds. On the lowest level the *stabilization task* is the actual lateral and longitudinal control of the car, i.e., the continuous adjustment of the (accelerator and braking) pedals to control the speed, shift gears, and steer the car by turning the steering wheel. Changes regarding the ability to achieve goals on one level normally influence the other levels as well. If the lateral acceleration is too high (sensing on the level of the stabilization task), this influences the guidance task by choosing a slower traveling speed. If a blocked road requires changes at the level of the guidance task (select a new path), this obviously influences the overall navigation task as well.

Secondary Driving Task (A) When dividing the driving task into two classes (e.g., ISO (2010b) and Wierwille (1993)) the term secondary driving task is used collectively for all other tasks other than the primary driving task. This might include for instance entertainment, communication with the outside or passengers, drinking, and eating.

Secondary Driving Task (B) When using a trisection of the driving task (Bubb 2003; Kern and Schmidt 2009), the secondary task refers to activities and functions that increase driving performance or driving safety such as activating the headlight, enabling cruise control, or adjusting the windshield wipers.

Tertiary Driving Task Tertiary tasks refer to all other tasks such as operating comfort, infotainment, or communication systems, or eating and drinking (Bubb 2003; Kern and Schmidt 2009).

For the remainder of this thesis, we use the trisection definition when talking about the driving task unless stated otherwise. When referring to literature where the authors used a bisection of the driving task, we refer to these secondary tasks (i.e., secondary and tertiary tasks) as *non-primary driving tasks*.

Using the trisected definition of the driving task, many of the tasks done while driving manually today can be classified as tertiary tasks. However, with an increasing level of driving assistance and automation, at some point the car takes over some or even all of the primary and secondary tasks (see Section 2.3.5). In this case, the traditional definitions of these tasks for the driver become obsolete and would require redefinition: When the vehicle is driving without human intervention, the driver can dedicate the time in the car to any activity beyond maneuvering and monitoring the vehicle. Thus, the former (manual driving) tertiary tasks will be the only remaining tasks and could become the (automated) primary tasks.

We do not expect an abrupt transition from manual to fully automated driving for normal road vehicles. Instead, we assume that driving a car in the near future might still comprise situations with different levels of automation during one ride. For instance, when starting a ride from home, the driver might enter her car, specify the desired destination, and start a (highly) automated ride through the residential area. Once she reaches the city center, due to construction sites, it is necessary to hand over to an assisted mode (e.g., only adaptive cruise control is available) or partially automated mode (i.e., the driver needs to monitor the vehicle). When entering the highway, the driver can finally switch back to a highly automated driving mode. During this part of the ride, she might for instance take a nap, read the latest e-mails, or watch the news. Since the last part of the route is a scenic and curvy road, the driver decides to switch to manually driving for this part of the route. Once arrived at the destination, she leaves her car and activates the (fully automated) remote valet parking service[22].

Looking at these different driving situations, it is beneficial to not have to distinguish between different driving task definitions for the various levels of automation. Thus, we propose to use alternative terms for the afore mentioned driving task,

[22] https://www.press.bmwgroup.com/global/pressDetail.html?title=bmw-innovations-at-the-2015-consumer-electronics-show-ces-in-las-vegas-360-degree-collision-avoidance&outputChannelId=6&id=T0198231EN&left_menu_item=node__5236, last access: 2014-01-22

focusing on the relation of an activity to maneuvering the vehicle–independent of the driving situation and level of automation:

Driving-related activity (DRA) As driving-related activities we define all activities that are related to maneuvering the vehicle (i.e., the traditional primary driving task for manual driving) or to increasing driving safety or performance (i.e., the former secondary task (B)). With assisted or partially automated driving, these activities might be less time-consuming than with manual driving, but would still comprise tasks such as monitoring the vehicle operation. With fully automated driving, such activities would almost diminish, leaving simple tasks such as setting the destination when entering the vehicle (see also NHTSA 2013).

Non-driving-related activity (NDRA) Tasks and activities that are not related to driving, such as operating comfort, entertainment, or infotainment systems, communicating with passengers or remote people, eating and drinking (i.e., the former tertiary task) are examples for non-driving-related activities. This will also include new activities that become possible with automated driving such as reading, watching motion pictures, or even sleeping. With an increasing level of automation, the amount of non-driving-related activities will grow and make up the largest part of the activities in the car in a fully automated driving scenario.

Even though these terms have partly been used in literature (NHTSA 2013; Radlmayr et al. 2014; Young, Lee, and Regan 2008a), the proposed terms of (non-) driving related activities have not yet been adopted and were sometimes even used without a clear definition. However, with the definition presented above, it should be easier to clearly describe tasks and activities in the car for manual, assisted, and automated driving situations alike.

2.3.2 Automotive User Interfaces and In-Vehicle Information Systems

When referring to the user interface, throughout literature various terms are used to describe the user interface used by the driver (and maybe the passengers) when driving a car. Common terms for this interface are “in-car (user) interface”, “in-vehicle (user) interface”, “car user interface”, and “automotive user interface”. All of these terms relate to the same user interface, i.e., the input and output elements that are integrated into the car so that the driver (or passengers) can control the available functions. We mainly refer to it as *user interface*.

A term which is related to using systems for information, entertainment, and communication is *in-vehicle infotainment system (IVIS)* (Harvey et al. 2011). Such IVISs often contain various components that allow for instance to listen to music (e.g., MP3, CD, DVD, or USB stick) or radio, to communicate with the "outer world" (e.g., telephone, text messages, e-mail), or to orient in a city / be guided to a certain location (navigation). Again, different terms are used in literature when talking about in-vehicle information systems such as the longer version "[advanced] in-vehicle information and communication systems" (AAM Driver Focus-Telematics Working Group 2006) or short infotainment system. In general, such systems "integrate most of the secondary functions available within vehicles" (Harvey et al. 2011) and aim at "enhancing the driving experience" (ibid.). Today, most of the IVISs are screen-based systems where input is for instance made by using touch (touch screen), buttons, rotary controllers, or speech. Output is given visually as content on the screen, on the dashboard, or on the head-up display and additionally sometimes through auditive feedback.

Especially within standards, the term *traffic and information control system (TICS)* (ISO 2002) is used frequently. ISO 15005:2002 defines TICSs as "single function, such as route guidance, or number of functions designed to work together as a system" (ibid.).

2.3.3 Attention and Driving Distraction

Already with the introduction of the windshield wiper which was invented independently in Europe (Prinz von Preuszen 1908) and the United States (Anderson 1903) at the beginning of the 20th century it was discussed whether such a technology should be allowed in the car. A public fear was that the windshield wiper would potentially hypnotize and thus *distract* the driver (Curry 2001).

In contrast, today drivers often perform a multitude of secondary and tertiary tasks on the road. While doing so, they split their attention between the different tasks. Consequently, their ability to react to the traffic situation and critical situations, i.e., the primary driving task, depends on the *attentional demand* of the different tasks. Especially when the attentional demand for the driving task is low (e.g., while driving on an empty, straight road), the driver often consciously decides to perform additional NDRAs. Already today this can be observed with assistance systems where drivers dedicate more time to NDRAs than when driving without assistance (Rudin-Brown and Parker 2004). However, during demanding traffic situations such as a high traffic volume at a 5-lane urban intersection the attention should be directed to the road. Also, with an increasing societal demand for productivity, people would like to use the "wasted time" (Green 2008) on the go. The number of available functions in the car might as well be a source of distraction, either since they offer communication or entertainment possibilities or since they overload (e.g., complex user interface (ibid.)) or underload the driver (e.g., in some assisted driving mode). Finally, also other people or objects inside or outside of the car can grab the driver's attention.

Sharing the (visual and manual) attention between driving- and non-driving-related activities can for instance be observed when a driver wants to select an artist and a specific song using the IVIS: Once the driving situation allows to perform additional activities, the driver might move the hand to the push-and-turn controller of the vehicle to operate the IVIS. At the same time, the gaze is directed to the display of the IVIS to find out the current status of the system and to navigate to the menus to select artists and songs. Since this might include multiple steps to perform and consume some time, the driver feels the pressure to direct the gaze back to the road after about 1.5 s (Wierwille 1993). After having monitored the driving scene, another glance to the interface will begin. Thus, the driver performs a visual sampling and chunks information into appropriate segments until the non-driving-related activity is completed.

Even though *driver distraction* is a term that is commonly used and understood, for a long time no unique definition existed for this term. As a broad description it refers to "any activity that diverts a driver's attention away from the task of driving" (Ranney, Garrott, and Goodman 2001). A similar definition is for instance given by Green (2008) as part of s a survey about different definitions for driving distraction:

> "A common theme is that distraction draws, diverts, or directs the driver's attention away from the primary task of controlling the vehicle." (ibid.)

We can distinguish driving distraction in various dimensions, such as the source of distraction, whether initiated by the driver or not, and which sensory processing is involved for a certain distraction.

In a report compiled for the American Automobile Association (AAA) Foundation for Traffic Safety, Stutts et al. (2001) define driver distraction as "when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task". In this definition, a triggering event distinguishes between distracted drivers and those that are inattentive or "lost in thought".

The Crashworthiness Data System (CDS) is a database operated by the National Highway Traffic Safety Organization (NHTSA) to collect a representative, random sample of different types of car accidents in the United States. Based on details from the CDS, Stutts et al. (2001) extracted two variables regarding driver *attention* and driver distraction. Here, attention and distraction are two dimensions to describe the driver's state: Attention describes the driver's overall relatedness to the driving situation. The different classes of attention are "attentive", "distracted", "looked but didn't see", "sleepy or fell asleep", and "unknown or no driver". Thus, driver distraction is one specific class of attention. This class is further split up into 13 different sources ("categories") of driving distraction. For general use outside of the crash data analysis, the last two sources can be combined to form a list with 12 sources of distraction (ibid.):

- eating/drinking
- events caused by objects or people inside or outside of the vehicle
- interaction with the entertainment system
- other passengers in the car
- moving objects in the vehicle
- smoking-related
- talking/listening on the phone
- dialing with a mobile phone
- using device/object brought into vehicle
- using device/controls integral to vehicle
- adjusting climate controls
- other distraction
- other/unknown distraction sources

Ranney, Garrott, and Goodman (2001) follow a different approach to categorize distraction. They propose four different types of driver distraction that are mainly related to sensory processing and driver behavior: *Visual distraction* occurs when the driver diverts her view away from the road, for instance to look at a map or observing the children on the back seat. *Auditory distraction* happens for instance when listening and responding on the phone, which can mask signals from the driving scenario. *Biomechanical distraction* occurs with biomechanical activities such as adjusting the radio where at least one hand is moved away from the steering wheel to complete a non-driving-related activity. Instead, *cognitive distration* can be observed when the driver is lost in thought or, for instance, is deeply engaged in a conversation with somebody else (inside or outside of the car). If we take the example where a driver is deeply involved in a phone call, we see that the different types of distraction can occur at the same time. The audio output of the remote party procudes auditive distraction, the conversation itself leads to cognitive distraction, and even biomechnical distraction can occur during handheld calling.

The previous definitions have also been picked up and used in the NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices:

> "The term 'distraction,' as used in connection with these guidelines, is a specific type of inattention that occurs when drivers divert their attention away from the driving task to focus on another activity. These distractions can be from electronic devices, such as navigation systems and cell phones, or more conventional distractions such as interacting with passengers and eating. These distracting tasks can affect drivers in different ways, and can be categorized into the following types: visual / manual / cognitive." (NHTSA 2013)

In these NHTSA guidelines also the potential safety issues related to driver distraction are highlighted:

> "Distraction means the diversion of a driver's attention from activities critical for safe driving to a competing activity. This diversion of attention may be due to non-driving-related tasks or to driving related tasks involving information presented in an inefficient manner or demanding unnecessarily complex inputs by a driver. Driver distraction is accompanied by an approximately proportional decrease in driving performance that can vary based on driver characteristics and roadway environment." (ibid., p. 128)

The potential for distraction of a non-driving-related activity depends on the workload/attentional demand of that activity and "the driver's 'willingness to engage' in that task" (Ranney, Garrott, and Goodman 2001). The latter factor is influenced by multiple aspects related to driving a car such as the driver profile, vehicle and interface properties, driving environment (e.g., traffic and weather), situational and task characteristics.

Pettitt, Burnett, and Stevens (2005) extend the previous definition and also differentiate distraction based on the source of distraction. This can either be internal or external sources. Furthermore, distraction can be driver-initiated or non-driver initiated.

As outlined before, a multitude of definitions currently exists to describe driver distraction. Recently, efforts have been undertaken to discuss these various definitions and narrow them down towards a concise definition (Foley et al. 2013). As a result of a questionnaire and a workshop among 21 experts in this domain, they agreed on the following high-level definition of driving distraction:

> "Driver distraction is the diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving." (Foley et al. 2013; based on Regan, Hallett, and Gordon 2011, p. 1776)

For further explanation, this high-level definition was extended by additional explanations and term definitions. First of all, it was clarified that driver distraction does exclude human states and conditions that impair the driver's capabilities to process information such as alcohol, drugs, or drowsiness even though an interaction between them and distraction can occur. In the context of this definition, attention comprises functions of the human brain, separated into orienting attention (select information from sensory input), executive attention (resolve conflicts among responses, regulate and modulate other (brain) network functions), and alerting attention (achieve and maintain an alert state). The notion of safe driving is then related to a reasonable and expected operation of a vehicle. For (driver) resources, Foley et al. distinguish between cognitive, auditory, vocal/verbal, visual, motoric, and other resources. A competing activity is then one or multiple activities that place(s) a demand on one or multiple of the afore mentioned resources similar or equal to those required for safe driving. The definition of "insufficient or no attention to activities critical for safe driving" is meant to also include such situations in which the driver has a delayed recognition of necessary information needed to safely accomplish the driving task. Different types of distraction can then be defined by relating to the competing demand on an individual resource (e.g., visual distraction or manual distraction) or the demand on a combination of resources such as visual-manual distraction. This allows to code any type of combination of distraction when necessary which is especially helpful during driver observation and analysis, such as during naturalistic driving experiments.

Welsh et al. (2012) provide a general definition for *attention*. They define attention as the "collection of processes that allow us to dedicate our limited information-processing capacity to the purposeful (cognitive) manipulation of a subset of available information" (ibid.). In other words, attention can be seen as the process "through which information enters into working memory and achieves the level of consciousness" (ibid.). According to Welsh et al. (ibid.), attention has three main characteristics respectively can be divided into three different categories: (1) Selective attention: attention is selective, i.e., only a certain subset of information is allowed to enter the (limited) processing system. (2) Focused attention: humans have the ability to voluntarily shift attention from one source of information to another. (3) Shared attention: within certain limitations attention can be divided such that one may selectively attend to more than one source of information at a time.

Preim and Dachselt (2010) provide details about attention switches: These are very fast in general. However, for auditive signals, this happens even with higher safety and speed. They also describe that attention switches may happen without a conscious decision in urgent situations while this happens based on conscious decisions normally.

2.3.4 Workload / Cognitive Load

Measuring the driver's workload is an important indicator to estimate the driver's ability to maneuver a car. An increased cognitive load may narrow the driver's perception and attention which in turn might reduce the margin of safety related to the primary driving task (Wierwille 1993).

For the concept of workload it is considered that workload "is a multidimensional, multifaceted concept that is difficult to define" (Gopher and Donchin 1986). De Waard defines (the driver's) workload as "the amount of information processing capacity that is used for task performance" (de Waard 1996). The differences between workload and distraction has been discussed by Mehler, Reimer, and Zec (2012). They state that distraction can also occur while the driver's workload is very low, e.g. through daydreaming. Thereby, the driver retains enough "capacity" to react appropriately on critical situations, which is not the case if a complex NDRA induces a high workload.

Various factors are known to affect the driver's workload (cf., (ibid.)). One of these factors is the context in which the driver is operating the vehicle: For instance, drivers might feel more stressed during heavy rain on a jammed highway than on sunny days driving along an empty road. Another influencing factor is the general condition of the driver that may change because of time pressure, current events, or the driver's mood. These factors potentially increase the workload for the driver and interfere with the driving task.

2.3.5 Levels of Driving Automation

At the moment, we can observe intensive efforts of car manufacturers, suppliers, and also IT companies (e.g., Google) towards the development of highly or fully automated and autonomous cars. Besides technological subtleties, legal limitations still prevent the approval of such vehicles as production vehicles (Lutz, Tang, and Lienkamp 2012; Schöttle 2014) in many countries[23]. So far, these legal constraints especially require that the vehicle operator (i.e., the driver) must be able to take over control at any time and also to continuously monitor the vehicle (BGBl. Teil II 1977).

Advanced driving assistance systems already support conducting the driving task in multiple ways[24]. ACC facilitates longitudinal control by maintaining or adapting speed and keeping the required distance to the lead vehicle. Additionally, an emergency brake assistant can slow down the car if the driver does not react fast enough. Similarly, lane keeping assistants, lane departure warning systems, and blind spot detection systems support lateral control. All together, these components cover a variety of functions that are required for automated driving. However, when using these assistants, the driver is still required to continuously monitor the systems and the driving scene. Thus, when performing NDRAs, the driver is in a dual-task situation where the driving task and the additional activities are performed simultaneously. In contrast, if a car is driving at least highly automated, the driver would not need to monitor the vehicle any more. This allows to fully dedicate to NDRAs with having to share attention between DRA and NDRA.

As automated driving gains importance, various national and international bodies analyzed the technical and legal aspects of driving automation and formed classifications for the different levels of (driving) automation. In Germany, the Federal Highway Research Institute (Bundesanstalt für Straßenwesen (BASt)) investigated these aspects and created the following classification (Gasser et al. 2012):

Driver only During the complete ride the driver is in charge of longitudinal and lateral control.

[23] see also http://www.zukunft-mobilitaet.net/17991/analyse/rechtslage-autonomes-fahren-regelungen-gesetz/, last access: 2015-10-30

[24] see for instance http://www.continental-automotive.com/www/automotive_de_en/themes/commercial_vehicles/chassis_safety/adas/functions/, last access: 2015-10-20

Assisted The driver is continuously in charge of either longitudinal or lateral control. The respective other task is performed by the (vehicle) system– within certain boundaries. When driving in this assisted mode, the driver constantly needs to monitor the system and must be prepared to take over full control at any time.

Partly automated The system takes over longitudinal and lateral contol (for a certain period and / or a specific situation). Identical to the assisted mode, the driver constantly needs to monitor the system and must be prepared to take over full control at any time.

Highly automated The system takes over longitudinal and lateral contol for a certain period in specific situations. During this time, the driver does not need to monitor the system. When required, the driver is asked to take over control with sufficient time reserve. The system recognizes all system limits. However, it is not able to lead into a state with minimal risk from every starting point.

Fully automated The system fully takes over longitudinal and lateral control in a defined use case. During this time, the driver does not need to monitor the system. Before leaving the use case, the driver is asked to take over control with sufficient time reserve. If this does not happen, the system will bring the vehicle to a risk-minimized state. The system recognizes all system limits.It is able to lead into a state with minimal risk from every starting point.

Similar definitions were issued by the National Highway Traffic Safety Organization (NHTSA) where automation levels are numbered from 0 to 4 (Trimble et al. 2014). Similarly, also SAE (2014b) issued a classification of automated driving levels. The mapping between the different definitions is illustrated in Table 2.1.

Most features of the first three levels of the SAE, NHTSA, and BASt definitions are comparable. During all of these levels, the driver is still responsible for monitoring the vehicle. For the first level (driver only / no automation / NHTSA 0), the driver has the sole responsibility of the full driving task. The second level (assisted / driver assistance / NHTSA 1) describes automation situations where the automated system (including various components) can assume limited authority over lateral or longitudinal control during certain situations. As defined for the corresponding NHTSA level 1 (Trimble et al. 2014), this excludes combinations of systems that allow the driver to fully take the hands off the steering wheel and the feet of the pedals. The third level (partially automated / partial automation / NHTSA 2) comprises situations where vehicle systems take over lateral and

Table 2.1: Comparison of the different definitions for levels of driving automations as issued by BASt (Gasser et al. 2012), SAE (2014b), and NHTSA (Trimble et al. 2014). Table adapted and extended from SAE J3016 (SAE 2014b) and http://cyberlaw.stanford.edu/loda (last access: 2015-10-20).

BASt level	**SAE level**	**NHTSA level**	**Execution driving task**	**Monitoring**	**Fallback**	**Driving situations**	**Driver interaction**
Human driver monitors vehicle system and environment							
Driver only	No automation (0)	0	Human driver	Human driver	Human driver	n/a	Dual-task
Assisted	Driver assistance (1)	1	Human Driver and system	Human driver	Human driver	Some	Dual-task
Partially automated	Partial Automation (2)	2	**System**	Human Driver	Human driver	Some	Dual-task
Automated driving sytem monitors driving environment							
Highly automated	Conditional automation (3)	3	System	**System**	Human Driver	Some	Sequential tasks
Fully automated	High automation (4)	3/4	System	System	**System**	Some	Sequential tasks
-	Full automation (5)	3/4	System	System	System	**All**	Sequential tasks

longitudinal control during certain driving situations. However, the driver is still required to monitor the systems and be ready to take over with no advance warning time (Trimble et al. 2014). In modern vehicles, an exemplary implementation of this level of automation is the traffic jam assistant where the car is able to keep the lane and maintain a safe distance to the lead vehicle (Cacilo et al. 2015).

The remaining levels describe those where the driver is not required to monitor the vehicle systems. For these levels, the definitions slightly differ between BASt, SAE, and NHTSA (see also ibid.). The BASt definition of highly automated driving describes a situation where the driver can disengage from the driving task but needs to be able to take over within a certain time when a take-over request (TOR) is issued by the vehicle. If this does not happen, the vehicle may not be able to bring the vehicle into a risk-minimized state (e.g., stop the car) in every situation since the human driver is the fallback. This is similar to the conditional automation definition of SAE. The SAE definition of high automation instead is comparable to the BASt definition of full automation which also includes a safe transition towards a risk-minimized state, i.e. a system-based fallback solution. For all levels mentioned so far, it needs to be mentioned that the automated systems may only work in certain driving situations and for a certain time period (defined use cases as mentioned in the BASt definition by Gasser et al. 2012). If the automated system can deal with any roadway and environmental condition, the SAE definition of full automation applies. This is similarly described for NHTSA level 4. The latter definition explicitly includes occupied and unoccupied vehicles. When driving fully automated in terms of the SAE definition or according to NHTSA level 4, the only necessary input by the (former) driver is the input of the destination.

For NDRAs an important paradigm change happens between the levels of partial and high automation (BASt levels). During partially automated driving the driver still needs to monitor and during driver-only or assisted driving he or she also is ‘ìn the loop” (Martens and van den Beukel 2013) and needs to (partially) maneuver the car. If an NDRA is performed at the same time, this involves a permanent switch between the driving-related activity and the NDRA and the driver is in a dual-task situation where attentions needs to be distributed between both types of tasks (Kahneman 1973; Wickens 2002). During higher levels of automation instead, the driver is “out of the loop” (Endsley and Kiris 1995; Martens and van den Beukel 2013) and does not need to pay attention to the driving activities. Thus, (s)he can dedicate the full attention to the NDRA while driving at least highly automated (BASt level).

The discussed taxonomies can easily be perceived as hierarchies that also imply the temporal order of the development of automated vehicles[25]. However, this is not necessarily the only way towards full automation: While one way is to gradually increment automation, e.g., with traditional vehicles, another approach is to deploy fully automated vehicles that only operate in a very limited context and whose range of operation is then gradually increased (International Transport Forum 2015). Especially for the definition of legal frameworks it may therefore be of interest to find alternative definitions for driving automation where cars have

[25] http://www.templetons.com/brad/robocars/levels.html, last access: 2015-10-20

Table 2.2: Criteria to describe driving automation. Table adapted and extended from Cacilo et al. (2015).

Factor	**Levels**		
Execution of the driving task	human driver	shared execution	system
Duration of automation	limited		unlimited
Monitoring by the driver	required		not required
NDRA allowed	none	conditional	any
Fallback when system limit is reached	human driver	human driver & system	system
Take-over readiness	any time	with ample delay	not necessary
Detection of system limits	human driver	human driver & system	system
System-based transition to risk-minimal state	not available		available
Support of driving situations	none	some situations	all situations

certain "basic capabilities over sets of roads and situations"[26]. Cacilo et al. (2015) list example criteria for the description of such automation capabilities. These criteria can be seen in Table 2.2. With this list, a vehicle that implements full automation as defined in SAE level 5 would comprise all capabilities as they can be seen in the rightmost column.

2.4 Car Accidents - Statistics and Prevention

According to the latest (preliminary) statistics, 3364 people died in 2014 being involved in accidents on German roads (Statistisches Bundesamt 2014). The increased use of active and passive safety technology allowed to reduce this number to about 15.8 % of the deaths on roads in 1970. The continuous reduction of road deaths is of special interest. For instance, the European Commission adopted plans to halve the road deaths between the years 2010 and 2020[27]. To reach this goal, multiple steps will be taken from increasing standards for vehcile safety, over improving training of road users, to an enhanced rule enforcement.

In order to minimize road accidents, it is important to analyze traffic accidents. In Germany, the Federal Statstical Office ("Statistisches Bundesamt") therefore

[26] http://www.templetons.com/brad/robocars/levels.html, last access: 2015-10-20

[27] http://europa.eu/rapid/press-release_IP-10-970_en.htm, last access: 2015-03-01

collects and analyses the details of all police-reported traffic accidents, neglecting (minor) accidents that have not been reported to the police. These statistics provide for instance insights on where (e.g., road type, state), when (day of the week, time, month), how (e.g., while turning left/right, exceeding speed limit, collisions with cars/pedestrians, road exceedences, ...), and under which environmental conditions (road situation, illumination, obstacles, parties involved) road accidents occur. The reports also document reasons for the analyzed accidents as they were reported by the involved parties and the police. Examples for collected reasons include fitness to drive, speed, overtaking, and distance keeping.

Another source for statistical information in Germany is the GIDAS project[28]. The goal of this project is to retrieve even more details about road accidents. Therefore, in two exemplary regions (Hannover and Dresden), a specialized team of accident analyst documents about 2000 car accidents per year by inspecting on-site accident location, vehicles and damages, (injured) passengers, and pedestrians. The analysis includes interviews with the involved parties and even post-hoc simulations of the documented accidents. This helps to retrieve details about the order of events and the mechanical implications of an accidents which in turn might be used to improve vehicle properties.

In a similar manner such data is also collected in other countries. For instance in the United States NHTSA runs the National Automotive Sampling System which contains two programs. The General Estimates System[29] collects general data on police-reported motor vehicle traffic crash reports. They also record additional details of a sample of accidents using the Crashworthiness Data System[30]. Additionally, the Fatality Analysis Reporting System[31] provides details about factors behind traffic fatalities.

One drawback of these statistics is that they rely on self-reported details regarding those details that cannot be recorded or measured once the accident has happened. This applies especially to pre-accident information, e.g., the activities which preceded the actual accident and that might have caused the accident in the first place. As an example, a crash may be caused because the following driver started braking much later than the vehicle in front. While this (final) reason may be present in accident reports, the original reason (e.g., drowsiness, distraction due

---

[28] http://www.gidas.org, last access: 2015-03-01

[29] http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+%28NASS%29/NASS+General+Estimates+System, last access: 2015-02-

[30] http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+%28NASS%29/NASS+Crashworthiness+Data+System, last access: 2015-03-01

[31] http://www.nhtsa.gov/FARS, last access: 2015-02-01

to calling or texting) often is not recorded or even asked for. Also, since this information is self-reported, one can assume that in certain cases negative behavior remains unreported as a matter of self protection of the driver who caused the accident. This makes it difficult to analyze the actual causes of road accidents in order to develop a suitable strategy to avoid accidents. While the CDS maintains at least some details about driver distraction or inattention, such information is still missing in the statistics available for Germany.

To allow for an analysis of road behavior in general but also of events directly before and at the time of accidents that is closer to reality, one potential alternative is to conduct observational studies. For such a naturalistic driving study (NDS), cars are equipped with technology to record driving behavior like speed, acceleration, and other car network information as well as cameras that record, e.g., multiple views of the forward and rear driving scene and the driver's cockpit (Lietz et al. 2011; Neale, Dingus, et al. 2005). If the technology is installed in those vehicles that the drivers own or use anyway, there is evidence that after a short adaptation phase the drivers disregard the installed technology (Neale, Dingus, et al. 2005) and drive as usually and, thus, provide more detailed insight regarding driver behavior than it would be possible with explicit test vehicles or with post-crash interviews.

The 100-Car Naturalistic Driving Study (Dingus et al. 2006; Neale, Dingus, et al. 2005; Neale, Klauer, et al. 2002) was one of the first large-scale studies to investigate driver behavior in a "natural" environment. As the name indicates, 100 cars were equipped with the afore mentioned technology for 12 to 13 months, producing a data set of 2 million miles driven, 43.000 hours of recording of in total 241 drivers. During the analysis, a special focus was on three type of events, namely "crashes, near crashes[,] and other 'incidents' ". During the study, 82 crashes (collisions with vehicles, fixed objects, cyclists, pedestrians, or animals), 761 near-crashes (conflicting situations that required action to evade a crash), and 8,295 incidents (conflicts with smaller evasive maneuver) could be observed. Only 15 of the 81 accidents were reported to the police which shows the clear advantage of a naturalistic driving study to also investigate minor events and accidents. When analyzing the data for driver inattention as a contributing factor for events, this inattention was split up into four categories: secondary task envolvement (i.e., involvement in NDRAs), fatigue, driving-related inattention to the forward roadway (e.g., looking at the rear mirror), and non-specific eye-glance. In total, 78 % of the recorded crashes and 65 % of the near-crashes were preceded by an event of of the four categories of inattention. The analysis showed that the distraction due to NDRAs was the largest category of inattention that contributed to crashes and near-crashes. Among distraction by NDRAs, the use of wireless devices (mainly cell phones) was the most frequent activity observed, followed by passenger-related activities (e.g., conversation), and internal distraction. For crashes with lead vehicles and minor collisions, inattention was a contributing factor for 93 % of the conflicts (Dingus et al. 2006, p. 349).

As the 100-Car Naturalistic Driving Study allowed first promising insights, a larger naturalistic driving study was planned within the Strategic Highway Research Program Two (SHRP2)[32] (Antin et al. 2011). In this study, over a period of one to two years, 1,950 cars were equipped with a similar technology to monitor in total about 3.150 drivers at six sites across the United States. Due to the large amount of collected data, the analysis of the experiment has not been published yet.

Naturalistic driving studies have also been conducted in Europe. As part of the EU-funded INTERACTION project[33] one of the first European studies has been conducted. In this project, an NDS was used to investigate and better understand how drivers interact with in-vehicle technology. The PROLOGUE project[34] aimed to assess the usefulness and feasibility of a large-scale NDS in Europe and to provide recommendations for the NDS itself (van Schagen et al. 2011). Building upon the experience gathered in the PROLOGUE project, the ongoing follow-up project UDRIVE[35] at the moment collects driving data in 7 EU member states (Spain, France, United Kingdom, the Netherlands, Germany, Austria, Poland) over a period of two years, similar to the SHRP2 project (Eenink et al. 2014). The DaCoTA[36] project used a reduced set of sensors for a prototypical naturalistic driving study. Here, especially no video data was recorded (Pilgerstorfer et al. 2011). The 2-BE-SAFE project[37] instead focused on powered two wheelers and conducted a natural riding study in Italy, Greece, the United Kingdom, and France (ibid.).

[32] http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/General.aspx, last access: 2015-03-10

[33] http://interaction-fp7.eu/, last access: 2015-02-20

[34] http://www.prologue-eu.eu, last access: 2015-02-20

[35] http://www.udrive.eu/, last access: 2015-02-20

[36] http://www.dacota-project.eu/, last access: 2015-02-20

[37] http://www.2besafe.eu, last access: 2015-02-20

2.5 Ensuring Usable and Safe User Interfaces through Standards and Guidelines

In order to design and deploy automotive user interfaces, a multitude of guidelines, rules, and standards exist that should be followed during the development process. All of these specification have the goal to facilitate interaction with IVISs, to ensure certain characteristics of automotive UIs, and limit driver distraction– across all car manufactures. Thus, these guidelines and standards mainly contain requirements or recommendations for the development of easy-to-use automotive user interfaces.

As individual transportation involves many stakeholders, different organizations issued guidelines and standards such as the United Nations, trade groups of car manufactures (e.g., the Alliance of Automobile Manufacturers (AAM), or the Japan Automobile Manufacturers Association (JAMA)), international and national standard-setting bodies (e.g., the International Organisation for Standardization), professional associations (e.g., SAE International), as well as government-related bodies such as the European Community or the National Highway Traffic Safety Organization (NHTSA), a department of the Department of Transportation of the United States. Also, local legislation often impose certain constraints on the design or use of technology in the car. Written from a European perspective, Schindhelm et al. (2004) provide a survey on existing guidelines and standards. Green (2009) provides a similar overview but from an American point of view. In the following, we will discuss the guidelines and standards that are relevant in the scope of this thesis.

2.5.1 Guidelines for Automotive User Interfaces

The Commission of the European Communities (2007) formulated the European Statement of Principles (ESoP) as a recommendation for ”(European) vehicle manufacturing and supply industry, (. . .) including importers and nomadic device suppliers” (ibid.), for both original equipment manufacturers (OEMs) or after-market providers. The guidelines primarily cover “in-vehicle information and communication systems intended for use by the driver while the vehicle is in motion, for example navigation systems, mobile phones and traffic and travel information systems” (ibid.). They do not only target at OEMs and after sale providers for integrated systems. Also, they apply to providers and manufacturers of nomadic devices (or enabling parts such as mounts etc.) that might be used while driving. The same holds for software, service, and information providers of products that are meant to be used while driving. ESoP considers all parts and components of the user interface that the driver should (not) use while driving. So far, they focus on information and communication systems that use visual and/or auditive output but exclude voice-controlled system and head-up displays. Also, issues not related to the user interface (e.g., electrical properties and material characteristics) as well as ADASs (since these might require immediate action by the driver) are excluded.

Similar to ESoP, there are numerous guidelines with similar goals and objectives of guiding auto user interface design, but the guidelines are targeted towards other markets. For Japan, these guidelines are the JAMA guidelines (JAMA 2004) and for the United States the AAM Guidelines (AAM Driver Focus-Telematics Working Group 2006). For instance, the AAM Guidelines focus at "design and installation issues related to devices designed to be used by a driver while the vehicle is in motion" (ibid.). The AAM Guidelines formulate the following objectives: The system should a) minimize adverse effects on driving safety, b) enable the driver to maintain sufficient attention to the driving situation while using the system, and c) minimize driver distraction and not visually entertain the driver while driving (ibid.). In contrast to the ESoP, the AAM guidelines also define testing methods and acceptance criteria for relevant principles.

The guidelines presented influence various aspects of IVISs. Common themes can be observed across the different guidelines (AAM Driver Focus-Telematics Working Group 2006; ESoP 2007; JAMA 2004):

Overall design principles These principles propose certain general requirements such as that the system supports the driver, but prevents hazardous behavior, allows for interrupted interactions, and remains compatible with the attentional demand of the driving situations.

Installation principles These principles provide recommendations on how and where to safely position controls and displays such that they do not obstruct the driver's view or reach and do not affect his perception (e.g., related to reflections).

Information presentation principles The system show allow for short glances to retrieve the intended information. It should also follow accepted standards regarding legibility, audibility, wording, icons, and abbreviations. Further, information related to the driving task should be accurate and timely and be prioritized based on its safety relevance.

Interaction with displays and controls These principles provide general hints how the interaction with IVISs should look like. for instance, to enable a safe handling, one hand should remain on the steering wheel and should not require long and uninterrupted manual-visual interactions but allow for resumable, user-paced sequences of interaction. System responses should be timely and clearly perceptible.

System behavior principles Related to certain situations, such as the vehicle in motion, additional principles are provided. For example, during vehicle motion, visually distracting information (e.g., TV and videos) should be disabled or presented so that the driver cannot see it. Also, the driver should be aware of the current system status, especially if for instance malfunction might impact driving safety.

Information about the system As a final set, certain information shall be available about each IVIS: The driver should receive adequate (correct and simple) instructions regarding installation, use, and maintenance. Also, it needs to be clear which functions may be used while driving and which functions are not.

As a summary for these principles, the AAM Guidelines formulate the following goals for the different categories:

- The design and location of IVISs shall allow that their use is compatible with the driving task (under routine driving conditions)
- The information presentation should not impair the driver's visual, auditive, or cognitive ability to safely perform the driving-related activities under routine driving conditions
- The design of the interaction with IVIS should under all reasonable circumstances allow the driver to maintain safe control of the vehicle, to feel comfortable and confident with the system, and to be ready safely respond to unexpected occurrences
- The presence, operation, and use of a system should be specified such that it does not adversely interfere with controls or displays that are necessary for the driving task or road safety

Driven by the awareness that 17 % of all police-reported car accidents in the United States involved some form of driver distraction[38] (NHTSA 2013), NHTSA

[38] 3 % of these involved some kind of interaction in the car

established (or is in process of establishing) a series of driver distraction guidelines. As a first publication in a series of guidelines, NHTSA published the Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices (ibid.). Theses “nonbinding, voluntary” (ibid.) guidelines are heavily based on previous guidelines, especially the AAM guidelines. They provide a couple of additions and integrate newer research results. The guidelines relate only to the use of integrated IVISs for non-driving-related activities when performed as visual-manual activities, i.e., the driver looks at the interfaces, performs manual input with his/her hand, and finally waits for for a (visual) response. For potentially suitable NDRAs the guidelines offer design recommendations in order to minimize their potential for distraction. The guidelines also discuss a list of NDRAs where NHTSA - based on their own research - came to the conclusion that they should not be used while driving. For tasks not mentioned in this list, the guidelines provide a test method and acceptance criteria to measure and rate the impact and suitability of a task to be executed while driving. Again, if a task does not match the acceptance criteria, NHTSA recommends to design the system in a way that this task cannot be operated by the driver while the vehicle is in motion.

When accounting for typical human driving behavior, obtaining compliance to the restrictive NHTSA guidelines is supposed to be be challenging. Of course, only technology should be allowed that is safe to be used while driving. However, typical human behavior shows that rules and even laws are sometimes ignored when the benefit of an activity is higher than the risk and consequences of being caught. As an example, many drivers still initiate handheld phone calls in their car even though this is prohibited in many countries. If we now assume that certain activities with IVISs might be banned for instance due to the definitions of the NHTSA guidelines, they might be performed on devices brought into the car (such as smartphones with a small display) that are less suitable or not even tested to be used while driving. Thus, one needs to be aware that a ban of certain activities performed with IVISs might cause additional issues.

2.5.2 Standards for Automotive User Interfaces

As the wording “guidelines” already states, the afore mentioned guidelines often are only recommendations for the different manufactures. Additionally, car manufacturers often need to follow published standards as well as contry-specific laws and directives. Most of the guidelines presented before take this into account and include and refer to corresponding standards that relate to the design of and interaction with IVISs in the car. During the discussion of international standards that have been adopted/accepted by local standardization bodies, we will mainly refer to the local standards. For instance ISO 15005:2002 (ISO 2002) has been developed as an international standard but was also accepted by the European Committee for Standardization as EN ISO 15005:2002 (CEN 2002). As a result, also DIN was obliged[39] to adopt the unchanged (but translated) version as DIN EN ISO 15005:2003 (DIN 2003a). All three standards are interchangeable.

For the development of IVISs, DIN EN ISO 17287 (DIN 2003b) defines a procedure to assess whether a certain IVIS or a combination of systems is suitable to be used by drivers on the go. It represents a rather high-level procedure for the development of systems that are easily usable since it addresses the assessment but does not provide specific items to assess or acceptance criteria.

Regarding ergonomic aspects of IVIS, ISO 3958 (ISO 1996) discusses operating distances in terms of “hand-reach envelopes” (ibid.) that define the boundary until where the driver can perform certain reach tasks with or without shoulder movement. To ensure that symbols for car functions and features can be (uniquely) identified and their functions easily be used, ISO 2575 (ISO 2010a) defines such symbols and colors that describe a system status (e.g., correct operation or malfunction). DIN EN ISO 15005 (DIN 2012) provides principles on dialogue management and presents compliance criteria. The principles of this standard complement the previously guidelines and present requirements and compliance procedures for dialogues to be used while driving. For instance one general requirement is that at least one hand should remain on the steering wheel. Also, the driver should be able to pick up relevant information in less than 1.5 s or be able to interact with eye glances of less than 1.5 s each. Regarding the system, feedback should be provided within 250 ms and the system should not limit the available time for input and present information as long as necessary. Dialogues should be consistent, controlable, appropriate for the driver (i.e., they consider the expectations, characteristics, and limits of the driver), and also error-tolerant. Ergonomic aspects of the visual presentation of IVISs are covered in DIN EN ISO 15008 (DIN 2011c) by providing a set of requirements and test procedures. For instance, certain requirements regarding image quality and legibility of (dynamic) content is given here. For the display of alphanumeric messages in IVISs SAE J2831 (SAE n.d.) provides information and design recommendations to be considered by OEMs and aftermarket systems.

When it comes to the design of voice user interfaces, SAE J2988 (ibid.) is a standard under development that will provide principles and guidelines on how

[39] see http://www.din.de/en/din-and-our-partners/din-in-europe/european-standards for details about the European and German standard development process, last access: 2015-10-30

to safely use voice user interfaces to control select features and functions of a vehicle. For auditive output DIN EN ISO 15006 (DIN 2012) provides ergonomic specifications for the design and integration of IVISs that use sound and speech output. Details are for instance given regarding sound frequency and loudness, information encoding, and redundancy of information (e.g., additional, time-synchronized visual output).

Another category of standards looks at (driver) performance measures as well as methods to test IVIS and their components. The following paragraphs provide an overview of essential standards that deal with this topic. More details about certain methods to evaluate automotive user interfaces are provided in the next section of this thesis.

SAE J2830 (SAE 2008b) for instance proposes a process to test the comprehension of icons and symbols used for active safety functions or other in-vehicle messages and functions. A collection of definitions for driving performance terms will be provided in the upcoming standard SAE J2944 (SAE 2013). ISO 26022:2002 (ISO 2010b, see also Section 2.6.3) describes the lane change test, a dual-task method for laboratory environments that can be used to estimate the demand of an NDRA when operating an in-vehicle interface such as an IVIS. The occlusion test is another method to test the visual demand (especially the time required to complete a task) by simulating shared attention between roadway and in-vehicle tasks through shutter glasses, i.e., goggles that can precisely obstruct the driver's view for a defined time span. This procedure is documented as ISO 16673:2007 (ISO 2007, see also Section 2.6.3). It is also part of SAE J2364 and SAE J2365 (SAE 2002, 2004), two standards that provide means to measure total task times / task completion times for navigation and route guidance functions and to recommend based on these timings which functions should be accessible while the car is moving. SAE J2364 is better known as the "15-seconds-rule" since it requires that the task completion time for uninterrupted navigation system tasks in a static situation is less than 15 seconds. The latter standard especially allows the estimation of task completions times without having to conduct experiments with real prototypes. While both standards address primarily navigation functions, Green objects that "there is no reason why J2364 should not apply to other visual manual tasks and other systems" (Green 2009). The Detection-Response Task (DRT) as a successor of the Peripheral Detection Task (PDT) is a rather new method to assess the attentional effects of cognitive load in driving and will be the content of the standard ISO/DIS 17488 (ISO 2015) which is currently under development.

Observing the driver's gaze is of special interest since it allows to quantify how drivers allocate their vision to the roadway or other objects and events in the vehicle. Thus, eyetracking, i.e., tracking the driver's gaze and visual behavior, allows to analyze for instance how the driver uses certain interfaces or how they distract the driver from the primary driving task. With this regard, (DIN EN) ISO 15007 provides "guidance on the terms and measurements relating to the collection and analysis of driver visual behavior data" (DIN 2013). The first part of this standard, draft DIN EN ISO 15007-1:2013 (ibid.), specifies the key terms and measurements that should be used to analyze and report the driver's visual behavior, especially glance and glance-related measurements, e.g., frequency, duration, and location of glances to specific area of interest (AOI). The second part of this standard, so far published as technical specification ISO/TS 15007-2:2014 (ISO 2014), offers guidance regarding the equipment and procedures for practical tests of TICSs and how selected metrics of visual behavior should be interpreted. The topic of driver visual behavior is also covered by SAE J2396 (SAE 1998).

Especially for warnings and assistance systems, a couple of standards have been defined throughout the last years. ISO/TS 16951 (2004) and SAE J2395 (2008a) provide methods to prioritize (simultaneous) messages and warnings and thus complement (DIN EN) ISO 15005. ACC interfaces are discussed in SAE J2399 (2014a). So are Forward Collision Warning systems in SAE J2400 (2003), Blind Spot Monitoring Systems in SAE J2802 (2010), and Road/Lane Departure Warning Systems in SAE J2808 (2007).

2.6 Evaluation Methods for Automotive User Interfaces

In the domain of desktop computers, focusing on evaluation methods such as usability and task performance (e.g., interaction errors, task completion time) for a single task (the one to be completed by the user) is often sufficient. However, in a vehicle we have a dual-task situation where the driver always needs to share attention between the most important primary task of maneuvering the car and other non-driving-related activities. Therefore, additional measures for the primary task performance need to be taken into account (Green 2012). These measures comprise information about lateral control (e.g., lane deviation, steering wheel activity), longitudinal control (e.g., maintaining speed, braking behavior), and driver reaction (e.g., recognition time for unexpected incidents) (Bach et al. 2009; Green 2012). The evaluation of an automotive UI therefore often combines measuring the task performance and usability of a secondary task as well as its influence on the primary task performance. Often, an analysis of performance-related measures is not sufficient, since it may only reveal extreme interface issues (Pauzié 2014). Thus, more advanced methods and measures are necessary for an in-depth investigation of how to improve which part of the UI (ibid.).

Evaluations of automotive user interfaces to assess safety and usability can be conducted in different environments, ranging from laboratory studies, simulator studies, up to real-world road studies on test tracks and field trials (Burnett 2009; Green 2012). The selection of a certain environment affects the validity of the results: road tests obviously have the highest degree of realism and therefore the external highest validity (e.g., regarding driving behavior) but the environment cannot be controlled (other cars, weather, etc.), which impacts reproducibility and internal validity. Also, potentially hazardous situations cannot be prevented completely. Simulator and or even simpler lab studies (even more) instead have a lower validity regarding aspects such as driving behavior but provide a much better reproducibility and comparability.

The following sections will first explain typical metrics that are used to evaluate and compare automotive user interfaces. Afterwards, it is shown how these metrics can be extracted in experiments across different environments.

2.6.1 Evaluation Parameters and Metrics

While conducting experiments with automotive user interfaces, different measures and metrics can be used to evaluate the interaction with these interfaces. These metrics mainly relate to the driver's performance regarding either the driving activity, the performance and quality (e.g., usability, user experience) of the interaction with the UI (i.e., the NDRA), or to the driver (e.g., the driver's workload).

Quantitative Measures

Similar to the desktop computing domain, objective measures such as *task completion time (TCT)*[40], *number of errors*, and pure completion of the intended task(s) can be applied to the AutomotiveUI domain. However, for driving-specific tasks, additional usability and performance measures can and should be taken. These relate to various aspects of driving and and the interaction with the interface. Also, we need to distinguish between the driving task and other NDRAs, since they also differ regarding the measurements to be taken.

[40] also called *total task time (TTT)*

Table 2.3: Selected driving-specific usability and performance measures. Table adapted from Green (2012).

Category	Statistics
Lateral control	Number of lane departures
	Mean and standard deviation of lane position
	Standard deviation of steering wheel angle
	Number of steering wheel reversals
	Time to line crossing
	Steering entropy
Longitudinal control	Number of collisions
	Time to collision
	Standard deviation of gap (time or distance to lead vehicle)
	Mean and standard deviation of speed
	Speed drip during a task
	Heading entropy
	Number of braking events over some g threshold
Visual behavior	Number of glances
	Mean glance duration
	Maximum glance duration
	Percentage of off-road glances greater than 2 s
	Total eyes-off-the-road time

An overview of typical objective driving-specific usability and performance measures is listed in Table 2.3. Measures related to the lateral control indicate the quality with which the driver keeps the car in the lane while driving. Accordingly, longitudinal measures describe the driver performance regarding speed, reaction, and distance keeping to lead vehicles.

The Standard Deviation of Lane Position (SDLP) is the most commonly reported lateral measurement, which represents the "dispersion of the lateral lane position" (SAE 2013). For a set $\{x_0, x_1, \ldots, x_n\}$ of n data points x_i of lateral positions and the mean lane position of the sample $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ SDLP can be calculated as follows:

$$\text{SDLP} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Another typical measure for lateral control is the number of lane exceedences during a ride (AAM Driver Focus-Telematics Working Group 2006).

Since many of the driving-specific measures can be defined in different ways, the use of common definitions is desired to produce comparable results across experiments (Green 2013). The standard SAE J2944 (SAE 2013) defines such driving performance measures and should be used when conducting and reporting automotive experiments. It also provides definitions for the different terms such as the lateral lane position being the "[l]ateral distance [. . .] from a specific point on the vehicle to a specified part of the lane" (ibid.). Further definitions are provided in the different standards and guidelines as those discussed in Section 2.5.2 before.

Also, the driver's visual behavior can be observed and measured using eye tracking technology (Harbluk, Noy, et al. 2007) to get an impression how the use of a certain interface affects the driver's gaze, such as the number of glances to the interface and the total duration of all glances or the percentage of glances greater than a certain time.

Using physiological sensors allows one to record various parameters such as heart rate, skin conductance level, and body temperature. In combination, these physiological measures offer the ability to infer details about the driver's workload.A detailed discussion of such technologies is part of Chapter 4 (Investigating the Driver's Workload).

Qualitative and Subjective Driver Feedback

In addition to objective measures, qualitative and subjective feedback can help to understand how users interact with an interface. Such feedback is especially related to the usability and user experience of an interface. Another dimension for subjective feedback relates to the driver's workload. In this section we present and overview of typical methods to gather qualitative and subjective feedback, laying a focus on those methods that were used in the studies described in the subsequent chapters.

ISO 9241:11:1999 (DIN 1999) discusses three main components of usability (measure): *Effectiveness* (i.e., users can complete their actual tasks and achieve their goals), *efficiency* (the amount of required resources to achieve a goal), and *satisfaction* (which level of comfort do the users experience when completing their tasks). While the first two aspects have already been discussed and can often be measured quantitatively, user satisfaction is often evaluated through subjective ratings, often retrieved through questionnaires that are handed out or otherwise processed during or after the use of a specific interface. For automotive experiments, often typical questionnaires known from other domains such as desktop computers and are used or slightly adapted to be used in the car.

A commonly used questionnaire is the *System Usability Scale (SUS)* (Brooke 1996, 2013). Initially designed to evaluate office computer systems, the SUS aims to provide a quick measure of user's subjective perceptions of the usability of a system during evaluations. Nowadays, it is used to evaluated a variety of technologies and systems (Bangor, Kortum, and Miller 2008) including automotive user interfaces. The questionnaire consists of ten questions with five response options (from "1 strongly disagree" to "5 strongly agree") for each question. The SUS has alternating items regarding positive and negative formulations to avoid response biases (Brooke 2013). For each user / questionnaire one overall score is thus calculated by adding the scores of each different item as shown below[41] (Brooke 1996):

- For odd-numbered items one is substracted from the user response.
- For even-numbered the user response is substracted from 5.
- The converted scores are added up and the sum is multiplied by 2.5 to calculate the SUS score for a single participant in a range between 0 and 100.
- The SUS score for a specific interface is then the average of all single user SUS scores

Bangor, Kortum, and Miller (2008) provide hints on how to judge specific SUS scores. They argue that "at least passable systems" should have SUS scores above 70, better products a score between the high 70s and upper 80s, and "truly superior" products better than 90.

To evaluate whether the interaction with an interface is intuitive, the *INTUI* questionnaire (Ullrich and Diefenbach 2010) is a suitable method. It tests four components of intuitive interaction, namely effortlessness, verbalizability, gut feeling, and magical experience.

The *AttrakDiff* questionnaire (Hassenzahl, Burmester, and Koller 2003) provides insights regarding the hedonic and pragmatic dimensions of user experience by using semantic differentials.

When it comes to the measurement of workload, a commonly used method for an subjective measurement of workload is the *NASA Taskload Index* NASA-TLX (Hart and Stavenland 1988). Initially, it was tested only with "cognitive and manual control tasks, complex laboratory and supervisory control tasks,

[41] See also http://www.measuringu.com/sus.php, last access: 2015-04-10

and aircraft simulation" (ibid.), i.e., mainly in the aviation domain. However, its use has soon spread to many other domains, including human-computer interaction with cars, computers, or portable devices (Hart 2006). In its original form, the NASA-TLX questionnaire considers six different dimensions, including mental demand (MD), physical demand (PD), temporal demand (TD), own performance (OP), effort (E), and frustration (F). The full procedure is for instance documented in the NASA-TLX Paper and Pencil Version Instruction Manual (Human Performance Research Group n.d.): For each experiment condition, the participants are asked to provide a *raw rating* r_d for each of these dimensions $d \in D = \{MD; PD; TD; OP; E; F\}$ on a separate subscale ranging from 0–100 (divided into 20 equal intervals).To cater with individual differences, increase sensitivity, and decrease between-rater variability, an additional weighting scheme is used to compute the overall workload. Therefore, for each type of task (or condition) the participants are once presented with all 15 possible paired comparisons of the 6 subscales. For each pairwise comparison, the participants need to select which of the two presented dimensions contributes more to the workload of the current task. The number of times that each dimension is selected is counted, producing the weights $w_d \in \{0; 1; 2; 3; 4; 5\}$ for each dimension ($\sum_{d \in D} w_d = 15$). The overall (weighted) task load W_{TLX} for a specific experiment condition and participant is the weighted arithmetic mean of the condition-specific weighted score for each dimension as shown in Equation (2.1).

$$W_{\mathrm{TLX}} = \frac{1}{15} \cdot \sum_{d \in D} w_d \cdot r_d \tag{2.1}$$

Since the weighting process can be cumbersome during the experiment, a common practice is to eliminate the weighting process (the score is then called *Raw TLX*, RTLX), to individually analyze the raw ratings r_d or the arithmetic mean W_{TLX} of the raw ratings as shown in Equation (2.2) (Byers, Bittner Jr., and Hill 1989; Hart 2006). Also, an examination of individual subscales allows to identify where differences in workload occur (Byers, Bittner Jr., and Hill 1989). Neglecting the individual weights w_d RTLX also solves the concern that a dimension that has never been selected as being more important in the pairwise comparisons would not have an impact on the final NASA-TLX score since the weight of the dimension is 0.0 in this case (Nygren 1991).

$$W_{\mathrm{RTLX}} = \frac{1}{6} \cdot \sum_{d \in D} r_d \tag{2.2}$$

The *Driver Activity Load Index* (DALI) is a derivative of the NASA-TLX and specifically adapted to the driving context (Chin et al. 2006; Pauzié 2008, 2014).

Table 2.4: Description of the dimensions used in the DALI questionnaire. Table adapted from Pauzié (2008), additional material provided by the author.

Dimension	**Description**
Global attention demand / effort of attention	Mental (to think about, to decide. . .) visual and auditory demand required during the test to achieve the whole activity.
Auditory demand	Auditory demand required during the test to achieve the whole activity.
Visual Demand	Visual demand required during the test to achieve the whole activity.
Tactile demand	Specific constraints induced by vibrations during the test.
(Situational) Stress	Level of stress during the whole activity such as fatigue, insecure feeling, irritation, discouragement. . .
Temporal demand	Pressure and specific constraint felt due to timing demand when running the whole activity.
Interference	Disturbance of the driver's state and consequences on the driving activity when conducting the driving activity simultaneously with any other supplementary task such as phoning, using systems or radio. . .

In this domain it has been used in various research projects (Pauzié 2014). The overall principles and procedure of NASA-TLX and DALI are the same. However, the dimensions of the DALI are slightly modified to better represent the driving context. The weighting procedure is similar to the one used for the NASA-TLX. However, for some research projects it has been eliminated to have a similar procedure and allow for a similar comparison like the RTLX (see for instance Kern, Mahr, et al. 2010). The different dimensions of the DALI questionnaire are: visual demand, auditory demand, tactile demand (sometimes skipped), temporal demand, effort of attention, interference, and situational stress. The first three dimensions form the perceptual load. Mental workload instead consists of the dimensions temporal demand, interference, and effort of attention. The Driver's state is reflected by the dimension of situational stress. In the questionnaire, participants rate the level of constraint for each of the factors on a subscale between 0 (low) and 5 (high) in comparison to the usual driving activity. Each dimension is explained verbally and textually to the participant as outlined in Table 2.4. Dimensions that do not apply to a certain experiment may be suppressed.

Peripheral Detection Task and Detection-Response Task

Another set of methods to assess driver distraction, mental workload, and visual distraction is the Peripheral Detection Task (PDT) (e.g. Martens and van Winsum 2000; van Winsum, Martens, and Herland 1999; Victor, Engström, and Harbluk 2008) and its successors the Detection-Response Task (DRT) (ISO 2015). PDT and DRT are artificial secondary or tertiary tasks in addition to driving, where the participant needs to quickly respond to a frequently and randomly occurring stimulus (e.g., light blink) by pressing a button. With this kind of sustained attention task (Victor, Engström, and Harbluk 2008) the reaction time and hit rate (a stimulus disappears after some seconds) can be measured which provide an insight to the current workload of the participant. In comparison to physiological measurements that allow a rather unobtrusive measurement but require complex interpretation, a PDT could be obtrusive (i.e., interfere with the driving task) but instead allows a straightforward measurement and interpretation (Engström, Johansson, and Östlund 2005).

As one of the earliest Detection-Response Tasks, the Peripheral Detection Task has initially been developed and used in a driving simulation by van Winsum, Martens, and Herland (1999). In this experiment, a red dot appeared in the driving simulation at a location in the driver's peripheral view and the driver had to react to this stimulus by pressing a switch that was taped to one of his/her fingers. The target appeared for one second (on average every 4 s, randomly choosen between 3-5 s) at a location 11-23 ° left and 2-4 ° above the horizon. This test is based on the assumption that with an increasing level of workload the reaction to such stimuli is slower or could even be missed–also due to visual distraction (Miura 1986). While the initial experiment used the PDT to measure the mental workload of driving (i.e., without evaluating distracting activities), it has soon been proven as a means to measure workload and attentional demand when performing additional tasks while driving (Olsson and Burns 2000, e.g.). The latter also applied the PDT in a real-world driving situation, the setup for this experiment can be seen in Figure 2.3.

Advantages of the PDT are that it is easy to measure and to assess and that it produces a rather large set of samples compared to other measures. Drawbacks of the PDT are that it is difficult to compare different PDT results since the procedure is not completely standardized. Since the visual stimulus appears at a fixed location in the car, visual distraction, i.e. gazes away from the road, influence the PDT measurements. Additionally, it is sensitive to lighting conditions (ibid.), difficult to be calibrated for a consistent stimulus location across all participants with different sizes and seat positions (ibid.), and might influence visual scanning which can be

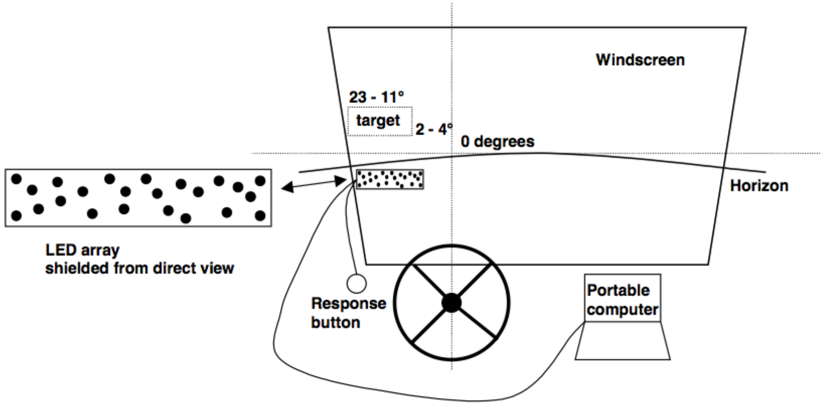


Figure 2.3: Exemplary apparatus of the Peripheral Detection Task for a real-world driving situation. An array of LEDs is mounted to the dashboard creating red dots as a reflection on the windscreen in the driver's peripheral view. When one of the LEDs lights up, the driver needs to respond by pressing a small button that is mounted to their left index finger. Image source: (Olsson and Burns 2000).

challenging when also collecting eye-tracking data in an experiment (Engström, Åberg, et al. 2005).

Since van Winsum, Martens, and Herland (1999) posed the assumption that the detection performance is not based on the specifics of visual perception, other modalities for the detection have been investigated as well. Examples are the Tactile Detection Task (TDT) where the LEDs have been replaced by a tactile vibrator that was attached to the driver's wrist (Engström, Åberg, et al. 2005). TDT has been shown to be as sensitive as the PDT to visual cognitive and cognitive-only tasks. A benefit of the TDT is that the driver cannot miss a stimulus just because (s)he was not looking to the forward view. An alternative location for the tactile vibrator could be the driver's neck as demonstrated by Merat and Jamson (2007). They also investigated auditory stimuli (*auditive detection task*, ADT) through a vehicle's loudspeakers as an alternative. Regarding the effect of operating an IVIS on the driver's stimulus response performance they did not find a significant difference between PDT, TDT, and ADT. As a reduced signal detection "can be directly associated with reduced attention towards unexpected events in the road" (ibid.) the authors propose to chose the most suitable modality and detection task for a certain experiment. For visual stimuli an alternative is to use a head-mounted LED that is in the visual periphery of the participant (van der Horst and Martens 2010). As with the tactile detection task, the target location is fixed relative to the driver.

To allow for a standardized test of IVISs using one of the previously mentioned variants, an ISO standard is currently being developed as s ISO/DIS 17488 (ISO 2015). As with recent literature (e.g. Bruyas and Dumont 2013; Ranney, Baldwin, et al. 2014) these tests are now referred to as Detection-Response Task (DRT) (Ranney, Baldwin, et al. 2014). With these terms, the head-mounted variant is now referred to as Head-mounted Detection Response Task (HDRT) (Conti et al. 2013), the tactile detection task is now called Tactile Detection Response Task (TDRT) (Young, Hsieh, and Seaman 2013). A rather new version is introduced as Remote Detection Response Task (RDRT) which combines ideas of the initial PDT and newer versions such as the HDRT. While located at a fixed location in the driver's forward view similar as the PDT, only one target instead of multiple is used. Once specific focus of the latest DRT research and standardization activities is the assessment of auditory and speech tasks (Harbluk, Burns, et al. 2013)[42].

2.6.2 Analytic Evaluation of In-Car Interaction

During the development and design of IVISs, often a multitude of interaction concepts and designs are created as drafts for the future user interface. Since each of them has an impact on a driver's performance, it is important to compare the different prototypes. For a detailed usability and driver performance analysis it is thus necessary to build functional prototypes and conduct experiments with them. Since the design and implementation of such prototypes is time-consuming and costly, such tests are often run for only a limited set of prototypes.

To allow the investigation of specific characteristics of interface variants even during early design stages with multiple variants, formal analytic approaches can be used as an alternative. With such evaluations, a system is for instance analyzed regarding its functionality, components, or features (see for instance Butz and Krüger 2014, p. 132). A benefit of such evaluation methods is that they often do not require tests with real participants since they rely for instance on predictive theories and models (Butz and Krüger 2014; Preim and Dachselt

[42] mentioned especially in the according presentation slides http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Supplemental/013_DA2013_slides.pdf, last access: 2015-03-20

2015). This allows for instance to evaluate concepts that may not be revealed to the public (Butz and Krüger 2014).

Initially invented for desktop computers, the Keystroke-Level Model (KLM) allows to model human performance and estimate task completion times based on previously empirically collected data for typical operations called operators such as key(board) presses and mouse movements (Card, Moran, and Newell 1980). Once the components and the design/layout of an interface are defined, the KLM allows to predict how long (i.e., the task completion time) it takes an (expert) user to complete a certain task using the interface under investigation. This timing is based on empirical measurements for the use of typical user interface elements. Thus, the task completion time can even be estimated for sketches of interfaces without a physical prototype. For the original KLM the following operators have been defined: Keystroke or button press (K), pointing to a target on a screen with a mouse (P), homing (i.e., movement) hands between keyboard and other devices (H), drawing straight line segments (D), mental preparation for a physical movement (M), and a system response time ($R(t)$).

The Keystroke-Level Model has already successfully been transferred to the automotive domain in different projects: Manes, Green, and Hunter (1997) investigate this topic and provided typical times for operators related to the entering navigation data. They adapted the KLM by providing revised values for keystrokes (based on key type and number of repetitions), and the mental operator. Also, they added multipliers that take into account the driver's age group (young, middle, older) as well as the lighting (dusk, dawn).

Green (1999a,b) was involved in defining the "15-second rule" as an acceptance criteria for navigation-system tasks: No continuous interaction with an IVIS should last longer than 15 seconds. As a validation method he built on previous work and proposed an adapted KLM. He introduced additional vehicle-specific operators like adapted version of the homing operator, i.e., the "reach near operator" (e.g., reaching from the steering wheel to other parts of the wheel, stalks or pods) and the "reach far operator" (e.g., reaching from steering wheel to center stack), as well as the "search" operator when searching for something on a display. Green also distinguishes different keystrokes. The work documented in that paper is related to the development process of the SAE standards J2364 and J2365 (SAE 2002, 2004). SAE J2365 combines these and other findings to determine the total task times for specific tasks, however it focuses on navigation data entry by combining several KLM approaches. In combination with SAE J2364, it describes a method for evaluating such interfaces in detail. The homing operators were further investigated by Pettitt, Burnett, and Stevens (2007).

Looking at the progressing design of automotive user interfaces, with new interface elements it can become necessary to add KLM operators that describe the use of these elements. Based on an observation of drivers using the in-car interfaces and building upon previous work, we developed an extended version for an automotive KLM (Schneegass, Pfleging, Kern, et al. 2011): For the operation of rotary controls and knobs such as volume or temperature knobs we introduced the "turn" operator (T). For a simplification of the model, usage times for specific turning angles (-180 °, -90 °,-45 °,45 °,90 °,180 °) have been defined. Similar to Green (1999a) we identified values for the homing (i.e., reach far/near) operator. Further, we adapted the "Finger Movement" (F) operator (Holleis, Otto, et al. 2007) to describe finger movements between two controls of the interface. Also, the observations showed that the keystroke operator had to be adapted. Since movements between keys are already modeled with the Finger Movement operator, in this model the Keystroke operator only accounts for pressing one button one or multiple times. The operator times depend on the number of pressings of the key with fixed values for one or two presses and a linear increase of time for each additional key press. One reason for this timing is the attention shift towards the interface that happens after the first key press. In the initial study, we observed that drivers shifted their attention between the different input and output areas of the IVIS. We therefore adapted the Attention Shift (AS) operator that was initially used for the mobile phone (ibid.) to describe the attention shift between different parts of the automotive user interface. Finally, we adapted the rules and timings for the Mental Preparation (M) task so that it fits to the automotive domain. In order to also take into account that the driving task requires permanent attention, we implemented a "wait function" ($W(a_i)$ to represent the "occlusion protocol" (Pettitt, Burnett, and Stevens 2007), i.e., a simulation of periodic glances between the road and the user interface.

Drawbacks of analytic methods such as the ones presented here are that they often focus on expert users which also do not make any errors (Preim and Dachselt 2015, p. 154). As further outlined by Preim and Dachselt (ibid.), this often limits evaluations to model unique tasks regarding routine interaction sequences. Often, it is difficult to use such models to predict the efficiency of an average user that uses a corresponding system (ibid., p. 154). However, it allows a comparison of different variants of a certain implementation (ibid., p. 154).

2.6.3 Lab and Simulator Studies

As simulator studies allow for a detailed control of environmental conditions, they are used in many experiments. For such experiments, a comprehensive set of (quasi-) standardized tests exists to chose from. These tests mainly investigate variations in complexity of the environment and the primary task. The following section presents a general discussion of driving simulators and and an overview of typical lab and simulator evaluation methods when it comes to testing automotive user interfaces.

Driving Simulators

The main advantage of using a driving simulator is the complete control of the environment (Kircher 2007). This allows the experimenter to set up the environment (e.g., road type, weather and traffic conditions, illumination, etc.) as intended and repeat the experiment with the exact same conditions for each participant (ibid.). Additionally, it is often possible to record more variables and data than with real vehicles. Since driving is only simulated, dangerous situations can be tested that would otherwise not be tested on real roads due to ethical reasons (Brooks et al. 2010; Kircher 2007; Reed and Green 1999).

When conducting simulator studies, driving simulators of different qualities can be used (Kircher 2007). While there is no clear definition regarding the fidelity of a simulator, we follow the common way to distinguish between low, medium, and high fidelity simulators.

Low fidelity simulators often only consist of a desktop setup comprising a single computer screen and a game controller (e.g., a gaming steering wheel) to control the virtual vehicle (Burnett 2009).

Medium fidelity driving simulators such as as the NADS miniSim[43] provide a more realistic setup. This may include features such as an extended field of view by using multiple screen and/or projectors or a mock-up or parts of a real car cabin such as dashboard, steering wheel and pedals, a real (fixed) driver seat, or doors. Depending on the intended experiments - and also the budget - different setup options may be chosen.

High fidelity simulators go another step forward an can comprise (parts of) a real vehicle cockpit, almost 360 degree projections, and even motion platforms. For realistic driving scenarios, motion platforms allow the driver to perceive typical movements of the car. The least complex setup of a motion platform consists

[43] http://www.nads-sc.uiowa.edu/minisim/, last access: 2015-04-20

Figure 2.4: The Stuttgart Driving Simulator provides a 360 ° simulation dome that fits complete production vehicles. Mounted on a motion platform with 8 degrees of freedom, it allows to also perceive motion as it occurs when driving in the real world. Image source: ©FKFS, used with permission.

of a movable driver seat. As an alternative, a car cabin or mock-up or parts of it are mounted on a movable platform. Latest simulators such as the Stuttgart Driving Simulator[44] (see Figure 2.4 even allow a full vehicle to be mounted on the platform (Baumann et al. 2010). This simulator dome uses an eight-axis motion platform to allow the motion perception of yaw, pitch, roll and heave and is able to provide longitudinal and lateral acceleration of up to 0.8 g. For the driver, 12 LED projectors provide a 360 ° view including correct images for the mirrors. Additionally, a multi-channel spatial audio system as well as force-feedback for pedals and the steering wheel complement the setup. In this case, movements of the vehicle controls are captured and translated into simulator events.

With increasing fidelity the costs of the driving simulator increase exponentially but they also increase the external validity since driving in such simulators is closer to reality. However, one needs to keep in mind that the participants are aware that they are being observed, which in turn might cause non-natural behavior (Kircher 2007). A drawback of driving simulations is that they can cause what is commonly known as *simulator sickness* (Brooks et al. 2010). In particular, participants can symptoms such as nausea, dizziness, headache, sweating, dry mouth, drowsiness, disorientation, vertigo, and vomitting (Brooks et al. 2010; Burnett 2009) similar as with motion sickness. Over time, multiple theories have been developed to describe how and why simulator sickness occurs (Brooks et al. 2010; Burnett 2009) including the most widely accepted (Brooks et al. 2010) sensory conflict theory by Reason (1978). Reason assumes that the conflict between the motion a person sees and the motion as it is perceived by the vestibular system contibute to simulator sickness. Since simulator sickness does not affect the whole population alike, tools such as the Simulator Sickness Questionnaire (Kennedy et al. 1993)

[44] http://www.fkfs.de/english/automotive-mechatronics/leistungen/driving-simulators/stuttgart-driving-simulator/, last access: 2015-04-20

help to exclude participants that might suffer from simulator sickness during an experiment. Additionally, certain countermeasures help to reduce the risk of sickness, including a high and stable frame rate, natural background lighting, air-conditioning, and the minimization of latency so that driver reaction and vehicle movement match (Baumann et al. 2010; Burnett 2009).

Occlusion Tests

Since lab studies especially focus on controlling the environmental conditions, even more abstract setups than driving simulations can be used. One example are *occlusion tests* that simulate the visual demand and can be used to test in-vehicle systems (AAM Driver Focus-Telematics Working Group 2006; NHTSA 2013; ISO 2007; Perez, Hulse, and Angell 2013; SAE 2002, 2004).

The assumption for occlusion tests is that the glance behavior for visual-manual in-vehicle tasks requires permanent attention switches between the in-vehicle user interface and the road, and thus allows only brief periods of vision to the user interface. Instead of requiring the participants to drive a simulated vehicle and permanently switch the attention between road and user interface, participants wear computer-controlled shutter glasses that precisely alternate between periods of vision (e.g.,1.5 s with ISO 16673:2007) and occlusion (e.g., 1.5 s with ISO 16673:2007). As an alternative, the display can be blanked during the occlusion phase (SAE 2004). During the occlusion period, the driver's view is obstructed completely and shall simulate the driver's view onto the road. For the rest of the time the vision is not blocked and the participant can interact with the in-vehicle user interface. This allows to conduct experiments in very simple environments, even at a simple desk in the lab or for instance in a parked car.

Using this technology, task performance, error rate, task completion time, and task continuation ease can be measured without the need for a driving simulation. An important measure is the Total Shutter Open Time (TSOT) which is the total time during which the participants' vision is not obstructed. For navigation tasks as defined in SAE J2364, this TSOT shall not exceed 20 s for a single task (ibid.). In comparison, when testing tasks without occluded / interrupted vision as it is also defined in SAE J2364, the (unoccluded) total task time ($\mathrm{TTT}_{\mathrm{Unoccl}}$) should be less than 15 s ("15-seconds-rule"). ISO 16673:2007 additionally defines a resumability ratio $R = \mathrm{TSOT}/\mathrm{TTT}_{\mathrm{Unoccl}}$ to compare user performance of uninterrupted and interrupted interaction. Ideally, R should have a value close or equal to one which means that the task can immediately be resumed after occluded phases.

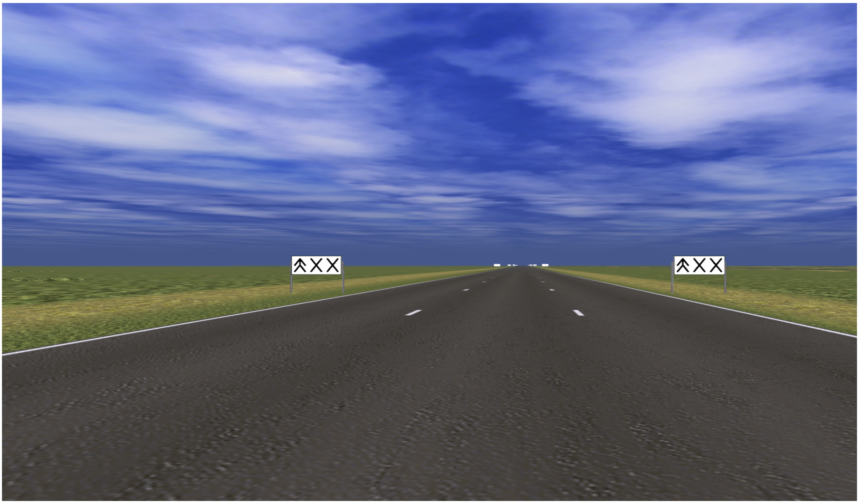


Figure 2.5: Examples for the scene and the signs used in the Lane Change Test: The driver is requested to change into the lane marked by the up-facing arrows quickly and efficiently as soon as the content of the signs appears. In this case, a change from the current middle lane to the left lane is indicated. Image source: Screenshot of the Daimler LCT software (Mattes 2003).

Lane Change Test

The ISO 26022 Lane Change Test (LCT)is a standardized, low-cost, and easy-to-deploy dual-task approach that allows human performance in a primary driving task to be quantitatively measured in conjunction with a non-primary driving task (ISO 2010b; Mattes 2003; Mattes and Hallén 2008). The experiment is performed in a simple driving simulation environment that comprises at least a computer display to show the driving scene and a gaming steering wheel to control the simulated car.

For each test condition, participants drive for 3 minutes on a straight, empty three-lane road at a constant speed of 60 km/h, i.e., for about 3000 m, and perform lane changes as soon as indicated by signs that appear in pairs along the roadside (consider Figure 2.5 for an example screen shot of the LCT). Between the lane changes, the driver is requested to keep the lane as accurate as possible. There are 18 signs per test track and they are balanced such that each of the six possible lane changes (left-middle, left-right, middle-right, right-middle, right-left, middle-left) occurs three times each. The mean distance between two consecutive signs is

150 m, ranging from 140 m to 190 m. With the constant speed, this results in time intervals between 8.4 s and 11.4 s between two consecutive signs. To avoid an influence of the screen/presentation quality or the driver's visual acuity, the signs are always visible but their content only appears once the distance to the car is less than 40 m. Each sign contains an arrow that denotes into which lane the driver needs to change and two X symbols for the remaining lanes. Further, the driver is instructed to change lanes "quickly and efficiently" (Mattes and Hallén 2008) and "the lange change should be completed before the sign is passed" (ibid.).

The design of the LCT allows for a laboratory-based experiment with an increased validity compared to a pure reaction time experiment. The driving situations makes the experiment more realistic: artificial stimuli are replaced by traffic signs, the lane change behavior is a replacement for pressing a button in a reaction time experiment. Also, the requirement to keep the lane and drive the vehicle try to create similar cognitive requirements as real driving (Mattes 2003). The LCT was one of the results of the joint research project on Advanced Driver Attention Metrics conducted by BMW and DaimlerChrysler (Mattes and Hallén 2008). A special focus was on building efficient surrogate techniques to measure driving distraction, i.e., techniques that may not necessarily provide the highest reliability but instead do not require expensive equipment (Mattes 2003). Thus, the LCT is especially helpful to identify extremely demanding NDRAs as a first step before conducting additional experiments.

In a typical experiment, the LCT is designed as a within-subject experiment. The participant starts with one or multiple test runs practicing the driving-related activity, i.e., the lane change test, without performing any additional task. Next, the non-primary task(s) shall be trained (without driving). Baseline data is then collected in another 3-minute drive without non-primary tasks. The actual dual-task situation is then either done in a blocked design where one (type of) NDRA is performed per run or in a mixed design where different (types) of NDRAs are repeated within one or multiple runs.

In order to evaluate the dual-task situation of performing an NDRA and the driving activity, it is recommended to evaluate both tasks alike. The reason for this is that participants might even with the same instructions share their attention in different ways between driving activity and NDRA.

The evaluation measures for the NDRA depend on the selected task. Typical measures include task completion time (TCT), also named total task time (TTT), and the number of errors.

For the driving activity, ISO 26022 proposes two models as options to measure driving performance and the influence of the NDRA on driving (ISO 2010b).

For the *basic model* this trajectory is the same for all participants. Based on the appearance of the signs and the road, it assumes that drivers have a reaction time of 600 ms, thus turns are initiated 30 m before a sign. Further, a lane change has always a length of 10 m. The *adaptive model* instead uses a baseline drive of each individual as a reference to better match the individual driving behavior. Especially, the start of a lane change, the length of the lane changes, and the overall lateral position of the vehicle in the lane are adapted for each driver.

With both models the mean deviation (*mdev*) of the actual path driven from the reference path trajectory shall be used as an indicator for the driver's awareness of the driving situation and their ability to safely control the vehicle and keeping the lane. *mdev* is calculated as follows (ibid.):

$$mdev = \frac{1}{S}\sum_i x_{\text{deviation},i}\frac{y_{i+1}-y_{i-1}}{2} \quad \text{with} \quad x_{\text{deviation},i} = \left\|x_{\text{position},i} - x_{\text{reference},i}\right\|$$

In this equation, $x_{\text{deviation},i}$ denotes the current lateral deviation, i.e., the difference between the current lateral position of the vehicle ($x_{\text{position},i}$) and the lateral position $x_{\text{reference},i}$ of the reference path trajectory. y_i is the current longitudinal position of the vehicle along the track and S denotes the length of the analyzed data segment. *mdev* is calculated only for those segments that are relevant for a certain experimental condition, i.e., invalid segments (e.g., when instructions are given) are simply excluded (ibid.). For a baseline ride without interaction, *mdev* is calculated for the section between the start sign and the location 50 m after the 18^{th} (last) lane change sign. This value is calculated for each participant and each experimental condition.

Since the influence of the NDRA shall be measured, times and sections where the driver received instructions longer than 1 s from the experimenter shall be excluded. The mean deviation is a compound measure that takes different aspects of performance into account: sign detection (delay of the detection, maybe even missing signs), quality of the lane change (slow / fast), and quality of keeping the lane.

When the mean deviation is measured in different tasks or with different interfaces, typical inference statics can be used to compare these situations. While LCT experiments are rather easy to use and provide quantitative data, one limitation is that the non-primary task needs to be compatible to the explained driving task. Thus, for instance tasks where the speed should be varied or steering movements should be done, cannot be conducted with an LCT experiment. Obviously, the LCT cannot be used with non-primary tasks that require steering wheel movements or speed variations.

AAM: Test Sequential Glances – Following Headway

Another test that is commonly used for driving experiments (Broy, Alt, et al. 2014, e.g.,) is described in the AAM Guidelines (AAM Driver Focus-Telematics Working Group 2006) when discussing criteria and verification procedures to verify that in-vehicle technology complies with the principles of these guidelines.

With regard to information presentation, principle 2.1 requires systems with visual displays to allow for brief, sequential glances to a user interface. One possibility to test the impact of a device-related task is to directly assess concurrent driving performance under dynamic conditions and compare the performance to that of accepted reference tasks.

To accept a certain NDRA, the influence on driving performance while conducting this task under standard test conditions (e.g., same driver and scenario) may not be greater than with doing "a scientifically-accepted reference task" (ibid.) with regard to lateral position control (i.e., the number of lane exceedences should not be higher) and car following headway variability. The latter requirement represents the need of the driver to maintain a certain distance to lead vehicles, react to speed variations, and lane changes of other vehicles. The measurement of car-following headway is actually the inter-vehicle range divided by the subject vehicle velocity, which results in a measurement in units of seconds. Therefore, for testing principle 2.1 one possibility is to set up a simulation environment where the main task is to follow a lead vehicle while maintaining a certain distance to this vehicle. The driving behavior is then measured during the experiment to allow a statistical evaluation afterwards.

2.6.4 Real-World Driving Experiments

Especially once prototypical automotive user interfaces evolve towards real products, it is of importance to also evaluate these interface in their real environment, i.e., in a real car. In order to not put the driver at (physical) risk, especially experiments with early prototypes are mostly conducted in the lab. While this is beneficial to control the complete environment and thus produce reproducible results as mentioned before (see e.g., Burnett 2009), the driving situation in a simulator is not really natural and thus, driver behavior can be different when using the same system and interfaces while driving a real car on the road. (Green 2012) (Kircher 2007) (Young, Regan, and Hammer 2003)

Even though experiments in the simulator and the real world might produce similar results, particular findings can be different (e.g., Bach et al. 2009). Thus, it is important to conduct tests in the real vehicle as well.

Test Track Drives

In order to get closer to reality, test track drives offer the possibility for experiments that are more realistic than simulator studies but still allow for the control of certain variables (Kircher 2007). Such experiments are conducted with equipped vehicles on roads or test tracks that are closed to the public. This allows to still control some conditions such as traffic, some types of road conditions (e.g., wet / dry), pedestrians or similar factors. However, other factor such as weather can not be controlled completely. Due to the closed track, it might be able to test slightly more dangerous situations than on real roads since traffic can be controlled (ibid.).

Road Trials

Road trials go beyond test track drives by bringing the experiment to public roads. Typically, such road trials are rather short-term (Burnett 2009) trials conducted in a single vehicle that is equipped with the necessary technology. Often the experimenter accompanies the ride on the back seat to operate the testing setup (Green 2012). In contrast to test track drives, especially other traffic on the roads is now a confounding factor for an experiment (Burnett 2009). However, certain variables can still be controlled, e.g., by starting a trial at a similar time of the day and by selecting the same route for all participants. Often, cameras are installed in these test vehicles to observe the driver's interaction but also the forward view or a view of the lane markings (Green 2012). Additional sensors can gather information such as steering wheel angle, brake pressure, speed, and headway (ibid.) or this information is recorded from the in-vehicle bus systems.

Field Trials and Field Operational Tests

In contrast to road trials, field trials take place over the span of multiple days, months, or even years (Burnett 2009; Green 2012). Often a whole fleet of vehicles is used to perform a field trial (Green 2012) and equipped with some additional technology, e.g., for recording of data to extract information about long-term effects caused by the use of a system (Burnett 2009). According to Burnett it can for instance be used to observe driver's acceptance of technology or to observe potential behavioral adaptation effects. One drawback of such studies is that they are often extremely expensive and require thorough preparation regarding ethical and liability aspects (ibid.).

During field trials, often no experimenter is present in the equipped vehicle. A *Field Operational Test (FOT)* is a “study undertaken to evaluate a function, or functions, under normal operating conditions in road traffic environments typically encountered by the participants using study design so as to identify real world effects and benefits” (Groups 2014). As outlined in the FESTA Handbook, for such FOTs drivers go through two conditions, one where the function is present and one where it is not. This is achieved through the experimenters controlling the system. The difference between field trials and FOTs is that field tests are smaller studies with a higher degree of experimental control (Victor, Bärgman, et al. 2010) while for FOTs the drivers often do not receive instructions regarding tasks to perform while driving or where to drive, i.e., they just use the car as they would do normally. Looking at naturalistic driving studies, these are also closely related to FOTs (SWOV Institute for Road Safety Research 2012). As outlined by these authors, the difference between both is that naturalistic driving studies only examine the driver’s behavior while FOTs evaluate new (market-ready) products and come with some kind of intervention to allow for different conditions to be tested. Also, the focus of Naturalistic Driving Studies is mostly on crash-explanatory factors while Field Operational Tests generally evaluate systems and functions (Victor, Bärgman, et al. 2010).

III

Designing the User Interface

Chapter 3

Supporting Non-Driving-Related Activities

As the previous chapters outline, driving a vehicle is still a complex task that requires the driver's full attention. This needs to be respected when designing automotive user interfaces. Adapted from other situations of daily life, we see an increasing need for facilitating non-driving-related activities in the car. During manual driving, this may be associated with a task-dependent risk of accidents depending on the driving situation (e.g., when texting while driving). Thus, automotive user interfaces that support such NDRAs should be designed in a way to not compromise safety but still allow performing the activity. On the other hand, with automated driving there will be times when the driving situation requires less or no attention by the driver and, thus, provides extended possibilities to perform NDRAs. We expect that these automated driving modes will even increase the need for additional or extended NDRAs to be supported and allowed in the car.

In this chapter, we provide an overall framework on how to support the developer of automotive user interfaces to design applications and systems that support non-driving-related activities in the car. We do so by presenting guidelines that aid the design and development process of automotive UIs and an exemplary model to support multimodal interaction and non-driving-related activities. Besides the driving context in general, we also try to cater for the different requirements of manual and automated driving modes to allow for a future-oriented design and development process that is applicable to the different driving modes alike.

3.1 User-Centered Interface Guidelines

Based on existing guidelines and standards as well as on current trends and observations, we developed a set of guidelines that are important for the development of future user interfaces for non-driving-related activities. The focus of existing guidelines and standards is often on driving safety and – related to this – ease of use. Developers need to respect these rules during the design of novel interfaces. However, by just following these rules it is still not guaranteed to build attractive and usable user interfaces. For common non-driving-related activities, we assume that drivers will use their mobile devices if the car does not support the activities in a convenient and usable way. Thus, our guidelines have a closer look at the user and the non-driving-related activity and try to provide hints on how to design enticing but safe automotive user interfaces for non-driving-related activities. The guidelines borrow for instance from the "Golden Rules of Interface Design" postulated by Shneiderman et al. (2009, Chapter 2.3.4) and usability heuristics as those by (Molich and Nielsen 1990) and their updated version by Nielsen[1]. We extend these guidelines for the automotive context. Shneiderman's rules can (and should) be applied to most interactive systems including the car. However, the car as an application domain has its own requirements. That's why our guidelines provide additional hints for the design process. We do not see our guidelines to support non-driving-related activities as a replacement of any of the previously mentioned standards and guidelines but as an addition to aid the design process of usable, enjoyable, and safe automotive user interfaces.

[1] http://www.nngroup.com/articles/ten-usability-heuristics/, last access: 2015-10-20

Guidelines for the Support of Non-Driving-Related Activities while Driving a Car

1. **Support a safe driving task**
   In situations where the driver's attention is still required to observe the driving scene and maneuver the vehicle or intervene (i.e., for manual, assisted, and partly automated driving), the driving task/the driving-related activities have the highest priority (see also ESoP 2007, information presentation principle IV). The system shall support the driver and prevent hazardous behaviour (see also ibid., design goal I). It shall not distract the driver in a way that is not acceptable (see also ibid., design goal III) and provide highly efficient interactions (see for instance Müller and Weinberg 2011).

2. **Use implicit and explicit context information where appropriate to support the interaction**
   Many activities in the car are done on a regular basis or based on the current situation/context. Thus, like a personal assistant, an ideal system might foresee the intended activity based on the current context and thus speed up the interaction. Such information may come from different sources such as *implicitly* sensed by vehicle sensors, physiological (driver) data, vehicle-to-vehicle or vehicle-to-infrastructure communication, the driver's schedule, or *explicit*, active intervention (e.g., switching to "away mode") by the driver to name only some sources. However, this needs to be done carefully to not confuse or upset the (experienced) driver (see "support internal locus of control" below).

3. **Use an adaptive interface to allow performing (safe) non-driving-related activities if the driving context permits additional activities.**
   If the current driving situation permits the performance of additional (non-driving-related) activities, the system should allow the driver to engage in suitable activities. These additional activities need to be compatible with the attentional demand of the current driving situation (see also ESoP 2007, design goal II) and driving mode. Thus, the system might need to adapt interaction capabilities and the choice of permitted activities based on the current driving context (i.e., driving situation and driving mode). Today, such functions are already used for secondary tasks such as adjusting the headlamps to the weight distribution in the vehicle, adaptive cruise control (adjust speed to the vehicles in front), or the windshield wiper that adapts its speed to the current intensity of rain (Preim and Dachselt 2010).

4. **Support a variety of non-driving-related activities that match the driver's preferences and needs**
   It is crucial that the in-vehicle systems support frequently used activities that are demanded by the driver. Often, nomadic devices (e.g., smart phones, tablet computers etc.) provide such functionality. As they are often brought into the car, it is crucial that the IVIS supports a safe operation of the driver-demanded activities as otherwise the drivers feel tempted to use their nomadic devices. Since these devices are often not designed to be used while driving, it is preferred to perform such activities through the IVIS instead of using the nomadic device directly.

5. **Allow for frustration-less denial, termination, interruption, and resumption of non-driving-related activities**
   In non-automated driving modes, multiple situations can occur where the driver needs to shift the attention back to the road. This is for instance the case during a longer interaction with an IVIS where regular glances to the road are required (see also ESoP 2007, information presentation principle I, interaction with displays and controls principles II/III). Also, when the driving situation changes to require (all of) the driver's attention, it might be necessary to interrupt a running NDRA. In these cases, the driver should have a frustration-less way to resume the NDRA once the driving situation allows to do so. When the task is resumed, ideally it is resumed at the point where it was interrupted or at a suitable point (see also ibid., interaction with displays and controls principle III). If the driver wants to initiate a non-driving-related activity in an inappropriate situation, a helpful response should explain the driver why the activity cannot be started and when or how the activity may be started again. In general, such situations should occur only rarely. Instead, where possible a context-sensitive interaction model (i.e., different interaction options in different driving contexts) might help to extend the range of situations where an activity may be performed. The more a certain function might be restricted in a certain situation the more the driver may tend to perform this activity using an (inappropriate) nomadic devices.

6. **Design easy-to-use, enjoyable, feature-rich interaction**
   By designing automotive user interfaces that are easy to use, that provide a positive user experience, and that provide a feature-rich interaction, it is more likely that the driver will consider the in-car UI as an alternative to nomadic devices. For any kind of application, the offered feature set should be similar to applications on other devices such as mobile phones or tablets.

At the same time, the in-vehicle system needs to be easy-to use in order to convince the driver to use the in-vehicle interface.

7. **Provide multimodal interaction modalities**
Multimodal systems allow the users to use different input (or output) modes such as speech, touch, touch gestures, or midair gestures in a coordinated manner to achieve their goal (Oviatt 2012). As further outlined by Oviatt, multimodal interaction can for instance be done by providing alternative/redundant ways to provide the same input (i.e., alternative input modes) or temporally cascading different input modes (e.g., starting with speech, switching to gesture input, and finishing with a button press). Such multimodal system - especially when offering redundancy - may reduce cognitive load since the driver does not have to worry about which modality to use for an input and tend to reduce interaction time (Müller and Weinberg 2011). Regarding multimodal output, additional modalities such as voice and sounds help to free the visual channel since the driver does not necessarily need to look at the interface. Driver preferences may vary between driving modes. Thus, drivers might prefer varying modalities in different situations. If a multimodal system offers different input and output modes, the driver can use the preferred mode in each situation. This may increase user acceptance as well.

8. **Consider interaction in different levels of driving automation and driving contexts**
When designing automotive user interfaces and interaction concepts, it is recommended to consider all different driving modes from manual driving to fully automated driving and to investigate how the interaction during each driving mode may be like. For some activities the interaction may be the same throughout all driving modes while for other activities different approaches might be necessary for the different driving modes. The same may apply also for different driving contexts. Therefore, it is beneficial to model the interaction depending on the current driving mode and context.

9. **Strive for consistency**
Throughout the intended interface, for similar situations and activities consistent sequences of actions should be required (see also Shneiderman et al. 2009). Also, common and identical (standardized) terminology, words, symbols/icons, sounds, colors, interaction metaphors as well as similar menu structures should be used across all tasks (see also ESoP 2007, design goal V). This helps to facilitate understanding within a certain user interface

as well as across different interfaces and cars as long as accepted standards are applied.

10. **Cater to universal usability**
    As proposed by Shneiderman et al. (2009), user interfaces shall provide suitable features across a broad range of users. This includes for instance assistance for novice users, additional features or shortcuts and faster interactions (see also ESoP 2007, interactions with displays and controls principle IV) for experts. The same holds for special requirements of users with different ages, technological diversity, or disabilities. Regarding elderly drivers, the special requirements of this age group such as a reduced reaction time, area of reach etc. need to be taken into account as well. A good system should support all of these users and by doing so, it improves the perceived system quality (Shneiderman et al. 2009).

11. **Offer informative feedback**
    For an activity conducted by the driver (s)he should receive appropriate feedback by the system (ibid.). The feedback may differ based on the user's action. For instance, only subtle feedback may be provided for small and frequent actions but more substantial feedback is given for larger and less frequent activities. The feedback needs to be timely and clearly perceptible (see also ESoP 2007, interactions with displays and controls principle VII).

12. **Design interactions to yield closure**
    For longer sequences of interactions, these should be structured to have clear groups of beginning, middle, and end (Shneiderman et al. 2009). For each of the groups, informative feedback shall be given once a group is finished to create a feeling of satisfaction and relief about the completion and/or to prepare for the next group. Ideally, interactions allow a consistent multimodal input where the driver may switch between modalities at discrection (Müller and Weinberg 2011).

13. **Prevent errors**
    The system should provide means to prevent serious errors performed by the driver (Shneiderman et al. 2009). For other errors, the system should provide means to easily detect and provide simple, constructive, and situation-dependent instructions or hints how to recover from an error (ibid.).

14. **Permit easy reversal of actions**
    If possible, the system should allow for reversible actions (ibid.). This reduces the driver's anxiety of erroneous actions and facilitates the exploration

of novel interfaces and unknown operations. Depending on the situation, the granularity of reversibility may vary between single steps, tasks, or complete groups of actions (ibid.).

15. **Support internal locus of control**
    Especially experienced users have a strong desire to feel in control of the system (ibid.) and not vice versa. This includes that they do not prefer sudden surprises or a change of familiar system behavior (ibid.). This rule may pose some challenges when it comes to context-dependent interruptions or adaptations of activities.

16. **Reduce short-term memory load**
    Already for desktop user it is known that users have a limited capacity for information processing in short-term memory (ibid.). This is also applicable to driving, where the driving task in manual and assisted driving modes already requires (almost) permanent attention. Thus, the interface should not require the driver to remember (and reuse) information.

17. **Apply international and national agreed standards and guidelines**
    National and international standards and agreed guidelines already provide best practices for many facets of automotive user interfaces. Especially regarding driving safety and ease of use, interface locations and characteristics(e.g., ESoP 2007, information presentation principle II), these standards and guidelines (for an overview see Section 2.5) define certain characteristics or expected behavior of an automotive user interface. This also holds for legibility, audibility, symbols/icons, words, abbreviations, and acronyms(see also ibid., information presentation principle II) where a re-use of common elements supports compatibility and ease of use across interfaces and manufactures. Since many of these standards and guidelines discuss only current manual and assisted driving modes, it needs to be verified how these apply to more automated driving modes.

3.2 A Context-Supported Model for Multimodal Automotive User Interfaces

Driving- and non-driving-related activities in the vehicle are highly influenced by the current situation. For instance, the demand by the driving-related activities may be high while approaching a jammed motorway intersection during heavy rainfall just after sunset. During such a situation, not much of the driver's attention

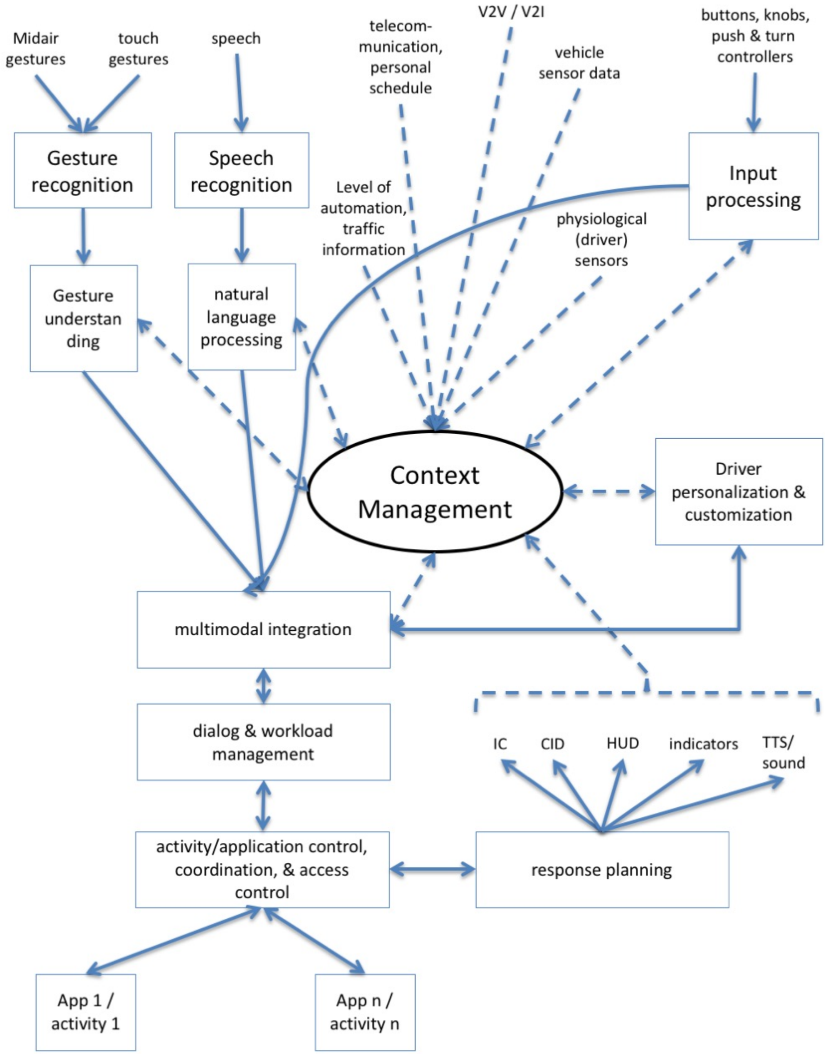


Figure 3.1: Example of the information flow of a multimodal automotive user interface, adapted from Oviatt (2012, Figure 18.7) and extended to a typical automotive environment. The different context components are shown as examples, a full overview of these components is given in Section 3.3.

may be used for additional non-driving-related activities. In contrast, while driving along a lonely 4-lane highway at noon having lane-keeping and adaptive cruise control activated, the attentional demand of the driving task is expected to be comparingly low. In such a situation, some of the driver's attention could partly be directed towards non-driving-related activities. This could even help to prevent fatigue and underload by keeping the driver active (Mehler, Reimer, and Zec 2012). When switching to fully automated driving on a highway at night, the car takes care of all driving-related activities. This makes room for a variety of non-driving-related activities, for instance related to entertainment, business, communication, or even relaxation and sleeping.

The three scenarios presented only show examples of the situations that are possible when driving a car. During a typical car ride, many of these situations may occur. As shown for the exemplary scenarios, interaction possibilities respectively the choice of suitable NDRAs may or should differ from situation to situation. In order to know when to allow, offer, or suspend certain non-driving-related activities, the in-vehicle information system should be context-aware, i.e., it should be able "to sense and act upon information about its environment, such as location, time, temperature or user identity" (Marmasse 1999).

As outlined in the guidelines of the previous section, automotive user interfaces should provide multimodal interaction possibilities. This includes various input modalities (such as interaction through buttons, knobs, direct touch input, touch gestures, midair gestures, body gestures, or speech) and output modalities (for instance visual output in the instrument cluster (IC), central information display (CID), head-up display (HUD), through indicator lamps, ambient light or through auditive output such as text-to-speech verbal information or sounds).

In order to combine the possibilities for input and output as well as taking into account the current context information, an information architecture such as the one depicted in Figure 3.1 could be employed to manage the interaction with the in-vehicle UI. This figure shows an exemplary information flow of a multimodal context-aware automotive user interface. Based on a concept presented by Oviatt (2012, Figure 18.7), our adapted model takes the specific requirements and properties of the automotive environment into account.

On the (explicit) input side, the different technologies sense the driver's input and corresponding software components perform an appropriate pre-processing if necessary. For instance, regarding speech input a microphone records the driver's voice, which is then passed to a speech recognition component to extract a textual representation the driver's speech. This representation is then further processed to understand the semantics of the spoken words and the driver's intention. For inputs such as the press of a physical button or a soft button on a touch screen, the processing requires less steps since the activation of the corresponding component already identifies which function or feature had been selected or (de-)activated.

To allow for a context-aware behavior of the system, a central context management component gathers all details about the environment that are currently available. This includes the interpretation of the different input components as well as all details about the vehicle, the surrounding environment as sensed through vehicle sensors or through information communicated to the car from other vehicles (vehicle-to-vehicle, V2V) or the infrastructure (vehicle-to-infrastructure, V2I), the driver (e.g., implicit input such as the driver's workload, sensed through physiological sensors) and his/her preferences (car customization, current communication needs, current schedule, etc.), as well as output that is presented to the driver by the interfaces of the car.

The interaction interpretations of the different input components are then fused in a component that performs the multimodal integration. This component aims to extract the driver's interaction intention. Besides the input from the different input components, the current context as sensed by the context management as well as existing settings regarding personalization and customization are considered while processing the driver's input.

The dialog & workload management component assesses the driver's workload based on the data from the multimodal integration and the available activities and application. It further controls the dialog with the user based on the current situation. Taking the driver input as well as current context information into account, another component coordinates and controls the running or selected applications or activities. This includes the reasoning whether a running activity is suited for the current driving context or which possibilities, representations, and responses etc. should be provided based on the current driving context.

Based on the decisions of the app/activity control component, the response planning component then decides how and which feedback of the current applications and activities shall be fed back to the driver. The corresponding output is then rendered on the corresponding device (e.g., presented on one of the screens or by generating voice or sound output). Also, the information which output is given to the user is fed back to the context management component.

3.3 Context Information to Support In-Car Interaction

Typically, driving situations as the ones presented in the previous subsection can be characterized by describing the context information of the corresponding situation. The context details depend on the driver and the passengers, date and time, the vehicle, the environment, and the intended route, Table 3.1 shows the most important details that may be used to characterize a certain situation and which may be used as input to the context management component of the information architecture described in the previous subsection.

Table 3.1: Context information types to support the interaction with automotive user interfaces.

Car Occupants	
Driver	Personal schedule: How does the current schedule look like? When does the driver need to be at the next event and where? Are there time sensitive events?
	Current mood: Is the driver happy, sad, angry, ...?
	Drowsiness/tiredness: Is the driver tired, drowsy, awake, ...?
	Personal preferences (e.g., regarding communication, entertainment, personal settings)
	Communication context: Does the driver communicate right now (e.g., in a phone call, texting, reading text messages? Is (s)he for instance waiting for a phone call / SMS?
	Driving behavior: Does the driver show an aggressive driving behavior? Is (s)he anxious, careful, ...?
	Age: How old is the driver? This may for instance affect driving behavior and reaction times.
	Physical characteristics: How tall is the driver? How strong is the driver? Such details may for instance influence the movement range and how physical controls are operated (which force is exerted),
	Current workload: Is the driver relaxed or stressed?
	Interaction: How does the driver interact with the vehicle right now? E.g.: Is (s)he holding the steering wheel and pushing the accelerator? Is (s)he performing any body gestures? Where do arms, hands, legs, and feet reside?

Continued on next page . . .

Table 3.1 – *... Continued from previous page*

Passenger(s)	Number and age of passengers: How many passengers are present? How old are they?
	Passengers' relation to the driver: What is the relation between the passengers and the driver (e.g., parents and children, business partners, spouse, etc.)
	Communication behavior: does a passenger require the driver's attention, e.g., by a permanent conversation?
	Shared attention: How much does the driver pay attention to the current driving situation? Does (s)he actively participate in the driving situation, e.g., by uttering hints and warnings?
	Route Characteristics
Route Characteristics	Date and time: what is the current time (or day/sunset/sunrise/night), day of the week?
	Route guidance: Did the driver enable route guidance?
	Destination: What is the current destination?
	Travel time: How long was the trip until now? How long does it take to get to the destination?
	Route selection: What are the characteristics of the roads on the way to the destination?
	Traffic: How is the traffic situation on the route?
	Vehicle
Vehicle	Speed: How fast is the car right now?
	Energy/Fuel: What is the current fuel/energy level?
	Engine parameters: RPM, ...
	Driving mode: Is the car in manual, assisted, or automated driving mode?
	Assistance: Which assistance functions are enabled?
	System status: are all systems running without errors?
	User interfaces: Which information is currently presented to driver and passenger(s)?
	Entertainment: Which entertainment features / functions are activated?

Continued on next page ...

Table 3.1 – *... Continued from previous page*

	Environment
Traffic	Traffic density
	Observable details about the surrounding vehicles: Speed, distance, driving behavior, driving direction, maybe size
	Pedestrians: Movements, size, danger?
Weather	Temperature
	Humidity
	Visibility
	Brightness
	Precipitation: Does it rain or snow?
	Wind
Road	Road type: For instance highway, city road, residential area
	Road surface: Paved, cobble stones, unpaved, snow-covered, ice
	Width
	Speed limit
	Travel restrictions
	Stored (Context) Information and Preferences
	Details and facts, that have been recorded and stored by the vehicle. These can be related to any of the other categories mentioned before.

3.4 Relation to the Chapters of this Thesis

The guidelines and model presented in this chapter aim to support the development of safe and enjoyable in-vehicle user interfaces to support non-driving-related activities in the car. As described, it is important that the system takes into account the current context information to know about the environment and especially the driver's current state. Today, an adaption of the user interface often distinguishes situations on whether the engine is running or not and whether the car is moving or not. To gather more details about the driver's status and workload, Chapter 4 discusses ideas on how to infer the driver's workload and presents a real-world study where we collected input for such workload systems: Drivers took part in a real-world study where we collected various physiological measurements and related them to the corresponding driving situations.

It is apparent that the interaction with the user interface needs to please the user and allow her/him to perform the desired activities. This is especially important to prevent the use of nomadic devices that do not consider the the special requirements of diving a vehcile and thus may not be appropriate to be used while driving. Also, with the rise of automated driving, we expect the number of available functions and suitable non-driving-related activities to rise massively. Already today, with 700 and more functions in medium to high-end vehicles it is not possibly any more to have a one-to-one mapping between (physical) controls and functions (Kern and Pfleging 2013), i.e. to have a separate button for each function. Thus, today many IVIS overcome this issue by using hierarchical display-based systems that are operated either via dedicated buttons, a push-and-turn controller or via touch input. Functions can be accessed using these input controls and by visually checking the selection on the central information display (CID). In order to provide an alternative with a flat hierarchy to such user interfaces and to provide a novel, interesting interaction style to the driver, we present a multimodal interaction concept in Chapter 5 that combines speech input and touch gestures on the steering wheel. Speech input alone is sometimes cumbersome when it comes to gradual manipulation or reversion of an input (Müller and Weinberg 2011). As the fine-grained input in our approach is done as gestures on the steering wheel, our approach overcomes this issue of speech input. In Chapter 5 we describe this multimodal interaction style in detail and present the two simulator studies that we conducted to evaluate it.

When it comes to which non-driving-related activities a car should support, we see a strong need for communication, entertainment, and office work. With this regard we present two case studies where we explore different NDRAs. First, we show a concept for safety-enhanced mobile communication in the vehicle (Chapter 6). For this case study, we analyzed the typical communication behavior of drivers in Germany and provide a concept to communicate especially context information to the communication partner outside of the vehicle. The idea is that this creates an awareness about the driving task by the remote communication partner as well as a reduction of call minutes an/or messages which in turn reduces driver distraction. Second, we present a concept for time-adjusted entertainment (media consumption) and/or working in the car (Chapter 7). Here, the idea is to make use the knowledge about the time span where the driver's attention is not required. Today, this may be the waiting time at a traffic light; in the near future this may be the time span until the end of the highway is reach, which might be the point where the driver needs to take over control from the vehicle. Based on this knowledge, suitable content is presented to the driver, making sure that the attention can timely be re-directed to the driving situation.

Chapter 4

Investigating the Driver's Workload

Since the interaction with an IVIS should not inappropriately distract the driver while he or she is in charge of driving, information about the current context is helpful to rate the appropriateness of activities and applications for the current driving situation. Of the different context-related items as outlined in Chapter 3 the driver's current state is of special interest for interactive vehicular applications. Ideally, the in-vehicle sensors and systems can provide a "zoom onto the driver" to an in-car application, i.e., a detailed model of the driver that offers context information such as what the driver is currently doing, what the current workload is, or what the current level of sleepiness is.

Such information is helpful or even necessary for many situations. For instance, one can imagine adaptive IVISs and applications, that offer different features or change their representation and behavior based on the current situation, especially by respecting the driver's current workload. One example for such an adaptive application is a navigation software where the screen content changes based on the current workload: While driving through a city with congested roads that require all of the driver's attention, the map shows as little details as necessary to not distract and overload the driver from the road. In contrast, on an empty highway, more details such as points of interest could be shown to allow an exploration of the surrounding and potentially even prevent underload or underarousal (Coughlin, Reimer, and Mehler 2011; Reimer, Coughlin, and Mehler 2009) that could happen in such a situation. For communication activities like texting or e-mail, a similar approach may be used: During highly automated driving the driving-induced workload is almost non-existent. Thus, free-form text entry is allowed through typing or speech input. Instead, during manual driving, text input is reduced to pre-defined messages. Text input may even be interrupted during extremely high workload situations such as during rush-hour on a very crowded road.

With a transition towards assisted and highly automated driving, more information about the driver will be required - not only for adapting the interface for potential NDRAs but also to fulfill the automation requirements. Hand-over situations where vehicle control is shifted between driver and car and vice versa may happen at any time during a ride. Thus, the car needs to know about the driver's state: Especially when a take-over request (TOR) requires the driver to take over from the automation due to system failure or inability (e.g., during rain and snow[1]), the vehicle systems need to ensure that the driver is alert and able to take over accordingly or which steps need to be done to prepare him/her for the manual or assisted ride. Thus, it is essential to know the driver's current state in order to model driver behavior (Islinger, Köhler, and Wolff 2011). The driver's state is also of interest for the opposite direction of hand-overs, i.e., from the driver to the car. For instance, the car could automatically take over the control for lateral and / or longitudinal control when the driver's workload increases, the driving behavior changes, or the visual attention deteriorates. This might for instance happens while the driver performs additional NDRA such as talking on the phone or texting.

The *driver state* consists of many aspects and may be monitored using various overt and covert measures of human behavior (Reimer, Coughlin, and Mehler 2009). As outlined by Reimer, Coughlin, and Mehler (ibid.) this includes electrocardiography (ECG) and electroencephalography (EEG) measurements, facial recognition, gaze concentration, gaze direction, hormones, pedal pressure, percentage of eyelid closure over the pupil (PERCLOS, Wierwille et al. 1994), photoplethysmogram, pupillometry, respiration, seat position, skin conductance level, steering wheel movement, grip position, and grip pressure. More abstract, Coughlin, Reimer, and Mehler (2011) outline the domains that potentially contribute to the driver state. This includes driving behavior (e.g., following distance, speed), biometrics (physiological data), visual attention (e.g., gaze concentration, gaze direction), emotion (inferred from facial expressions and voice), environment (weather,

[1] http://www.motor-talk.de/news/bei-diesem-auto-ist-langeweile-das-ziel-t4941424.html, last access: 2015-05-17

traffic, road geometry), vehicle performance (e.g., acceleration, breaking), and driving style. They describe the driver state as "the overall physical and functional characteristics of the operator such as his or her level of distraction, fatigue, attentional capacity, and mental workload" (ibid., p. 17).

This chapter is partly based on the following publications:

- Stefan Schneegass, Bastian Pfleging, Nora Broy, Frederik Heinrich, and Albrecht Schmidt (2013). A Data Set of Real World Driving to Assess Driver Workload. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 150–157. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516561 [a]
- Bastian Pfleging, Drea K. Fekety, Albrecht Schmidt, and Andrew L. Kun (2016). A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. (CHI '16. San Jose, CA, USA). ACM: New York, NY, USA, May 2016, pp. 5776–5788. DOI: 10.1145/2858036.2858117

[a] Parts of this paper are also included in the PhD thesis of Stefan Schneegass

In this chapter, we focus on driver workload which can be seen as one part of driver state. We wanted to understand driver behavior and retrieve information about the driver's workload on the road. To do so, we conducted a real-world driving experiment on roads around Stuttgart where we used physiological sensors to monitor driver behavior and objective workload and enriched this information with post-hoc subjective ratings of the workload (by the drivers) after the experiment. With this experiment, we wanted to map physiological parameters to driver workload and driver state. Also, the assessment of the workload itself during different situations is of interest. One idea is to identify patterns how workload is affected by certain factors, for instance during specific traffic situations or on different road types. Another contribution is the data set itself: We recorded all parameters and released the data set to the public in order to make it available for other researchers and research projects. This chapter will discuss the use of driver state information in detail and present the experiments and their results. The large-scale study was conducted and evaluated together with colleagues, in particular with Stefan Schneegass. In the context of this thesis, I report specifically on mapping physiological parameters to the driver's state and workload. Stefan's focus instead is on data acquisition and processing.

4.1 Related Work

As already outlined in Section 2.3.4 the driver's workload is an important indicator that can be used to estimate the driver's ability to maneuver a car. Since drivers perform already today many non-driving-related activities besides their original driving tasks, such an indicator is already an important input to automotive applications. In this section, we first discuss the concept of (mental) workload as well as its influence and importance in driving situations. Additionally, we provide an overview of different methods to assess subjective and objective workload measures. Unless explicitly stated otherwise, the term *workload* is used in this thesis as a short form of *mental workload*.

4.1.1 Mental Workload

Being discussed in multiple domains, there is so far no universally accepted definition of mental workload (Collet et al. 2003). As described by Gopher and Donchin (1986) workload is used as a term to "describe aspects of the interaction between an operator and an assigned task" (ibid.) or system. In this case, tasks and systems are described by their structure and on the side of the human operator capabilities, motivation, and state are of importance (ibid.). As further specified, workload can be seen as "a cost the operator incurs as tasks are performed" (ibid.). Similar as with physical workload they explain that a failure to perform when in general capacity is available indicates that usage limits exist. This concept is based on the model of a human organism where the information processing system which is used to perform a task consists of sensors to gather information and effectors to respond. This said, the implication is that the information processing system has a limited capacity. As outlined further, mental workload can thus be seen "as the difference between the capacities of the information processing system that are required for task performance to satisfy performance expectations and the capacity available at any given time" (ibid.). With this regard, *task difficulty* "is thus manifested by a difference between the expected and the actual performance" (ibid.).

Wickens and Tsang (2015) define workload as the "relationship between the resources required to carry out a task and the resources available to, and hence

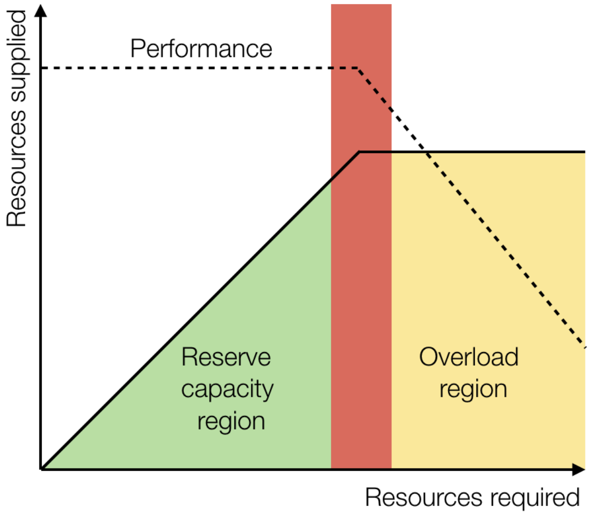


Figure 4.1: The supply-demand function as defined by Wickens and Tsang (2015), based on a resource concept by Kahneman (1973): The x-axis depicts the resources that are required by one or multiple tasks. The y-axis shows the actual level of effort or resources supplied by the human operator (solid line) respectively the level of performance with regard to the task(s) (dashed line). From the origin to the red line or zone, resources can be provided as requested (reserve capacity region). Beyond this line or zone, no further resources can be provided and instead task performance decreases (overload region). Figure adapted from Wickens and Tsang (2015).

supplied by, the operator" (ibid.). As depicted in Figure 4.1, they furthermore employ a supply-demand function to explain this concept: To perform a single task or a set of tasks (multitask workload) certain resources are required. As long as resources are available, an adequate amount of resources is provided by the human operator and the level of performance is satisfactory. When the limit of available resources is reached but the demand increases further, supply of resources is limited and in turn performances decreases. In Figure 4.1 this is marked by the "red line" or zone (the zone is used to explain the uncertainty about the real limit). Thus, the red zone or line divides the resource space into two zones, namely the one of *residual resources* or *reserve capacity* (where resources are available) and the one of *workload overload* (where there is a a lack of available resources).

Additionally, Wickens and Tsang (2015) explain that we need to distinguish that a loss of performance does not only happen due to workload overload but may also happen due to other factors such as inappropriate illumination, noise, lack of knowledge, or unclear instructions (so-called data limits). Resource demands can be single-task demands or multitask demands (ibid.): For a single task the red line may be crossed for instance when the human bandwidth is not sufficient such as when the response time to an observation is too long. With multitask demands (e.g., while driving and performing additional NDRAs) it happens that performance drops for one of the tasks if the resources are exceeded. Similarly, Wickens and Tsang (ibid.) distinguish reserve capacity from *underload*. They characterize the latter as periods where nothing is done at all. Underload and other effects such as fatigue, boredom, and lack of vigilance, happen to the very left of the diagram in Figure 4.1. The reserve capacity region instead focuses mainly on situations where the human operator is already somehow busy but with expected performance.

Another differentiation can be made between workload and multitasking. While these two concepts are closely related and partly overlap (Wickens 2002; Wickens and Tsang 2015), there are differences between both. For instance, workload can be caused already by a single task (Wickens 2002). The multiple resource theory (see for instance Wickens 2002, 2008) as a theory of multitasking for instance uses an architecture that comprises components related to demand, resource overlap, and allocation policy (Wickens 2008). It focuses mainly on the mechanisms to predict success and failure of certain tasks rather than focusing on the overall demand for resources of these tasks, which is subject of workload theories (Wickens and Tsang 2015).

De Waard (1996) discussed the driver's workload as well. By describing workload as "the amount of information processing capacity that is used for task performance" (ibid.), he also relates the driver's workload to the hierarchically layered primary driving task, the latter being similar to the definition by Bubb (1993) as outlined in Section 2.3. Demands at each level can exceed reserve capacity and, thus, impact performance of tasks at a different level. Driver performance measures are suitable on each level, for instance through steering wheel movement on the lowest level (stabilization task), car-following performance on the intermediate level (guidance task) and route choices (errors) on the strategic level (navigation task).

The differences between workload and distraction have for instance been discussed by Mehler, Reimer, and Zec (2012). They state that distraction can also occur while the driver's workload is very low, e.g., through daydreaming. Thereby, the driver retains enough "capacity" to react appropriately in critical situations. In contrast, this is not the case if a complex task (e.g., multiple NDRAs) induces high a workload.

Mental workload and stress are also discussed in international standards. DIN EN ISO 10075-1 (DIN 2011b) defines terms in the domain of mental workload, mental stress, and mental strain. In this standard, *mental stress* is defined as the total of all assessable influences that reach a human being from external sources and affect it mentally. *Mental strain* instead is the immediate (i.e., non-long-term) effect of mental stress on an individual person, depending on the individual typical and current preconditions, including personal copying styles. Thus, mental strain includes personal differences of the individual. The standard also states that any activity can be mentally stressing. Mental stress affects mental strain of human beings (ibid.). As outlined further, immediate effects can facilitating (e.g., warming up or activation) or impairing (e.g., mental fatigue or fatigue-like states such as monotony, reduce vigilance, or mental satisfaction). Longer-term effects may be practice or learning effects (ibid.). Additional explanations for this standard are provided in DIN SPEC 33418 (DIN 2014). DIN EN ISO 10075-2 (DIN 2000) provides guidelines how to design work systems while taking into account mental workload. DIN EN ISO 10075-3 (DIN 2004) provides additional hints on how to design, rate, and select methods to measure mental workload.

While the analysis of workload and strain initially focussed on physical strain, e.g., regarding the arrangement and use of input and output devices in production environments, today especially mental strain is investigated, for instance to prevent long-term harm caused by mental strain (Preim and Dachselt 2010, Chapter 6).

As described by Mehler, Reimer, and Zec (2012) the driver's workload is affected by various factors. One important factor is the current context in which the driver is operating the vehicle: Heavy rain or congested highways might induce more stress (i.e., a high workload) than a situation where the driver enjoys an empty scenic byway on a sunny day. Of course, also the general condition of the driver affects the workload, which may change due to time pressure, current events, or the driver's mood. These factors potentially increase the workload for the driver and interfere with the driving task.

4.1.2 Assessing Mental Workload

Different metrics to assess the human workload have been explored, also in the automotive domain, to assess the driver's workload. The metrics can be classified as subjective (e.g., asking the user), physiological, or performance-based (Gawron

2008; Miller 2001; Wickens and Tsang 2015). In the following, we outline typical methods on how to assess workload in general and also how this has been used in the automotive domain so far.

Performance-based Metrics

Performance-based measures assume that task performance will degrade with increasing workload (Gawron 2008). Primary task performance metrics directly link to system performance (Wickens and Tsang 2015). Instead, secondary task performance measures can be used when a secondary task is performed in parallel to the original task in order to consume reserve capacity (ibid.). When the workload of the primary task increases, less reserve capacity is available which in turn leads to performance degradation of the secondary task (ibid.). Gawron (2008) outlines a variety of existing performance-based metrics.

The "n-back" task is an example for a performance-based method to infer workload (Kirchner 1958). For this task, a sequence of stimuli is presented to the participant and the participant is required to reproduce the stimulus that was presented n steps before. In its original form, the stimulus was a light that appeared at different locations and the participant had to recall this location n steps later. With an increasing load factor n, the task becomes more difficult. A related method is the delayed digit recall task where digits are read out to the participant and the participant needs to repeat the digit that was presented n steps before[2] (Mehler, Reimer, Coughlin, et al. 2009; Mehler, Reimer, and Dusek 2011). This is meant to demand a comparable set of mental resource such as when responding to a phone call, interacting with an IVIS, or talking to passengers (Mehler, Reimer, and Dusek 2011). Mehler, Reimer, Coughlin, et al. (2009) employed the task to observe how heart rate (HR), skin conductance response (SCR), and respiration change with increasing workload. They found that all three measures "appeared to plateau" (ibid.) at the highest level of workload (2-back recall task) together with a slight drop in driving performance.

The peripheral detection task respectively the detection response task as described in Section 2.6.1 is another approach in which the user has to react to a stimulus in the peripheral field of view as fast as possible. Here, reaction time and detection rate provide insights of the user's workload level. Jahn et al. (2005) showed in a field study that the PDT is a useful method to assess the driver‘s workload. Knappe, Keinath, and Meinecke (2008) found that an increased workload seems to induce micro movements of the steering wheel.

[2] see also http://agelab.mit.edu/delayed-digit-recall-n-back-task, last access: 2015-10-20

Subjective Metrics

Subjective measurements of workload happen when the participants directly estimate the workload that they experience while performing a certain task. Often, during such questions, they are asked about the difficulty (Gopher and Donchin 1986) or demand of a task instead of using the term workload in such interviews.

For subjective measurements, unidimensional metrics provide a single score to rate the overall level of mental workload. One example is the Bedford workload rating scale (Roscoe and Ellis 1990) that has been used to assess pilots' workload. Based on a decision tree with at max three yes/no questions ("Was it possible to complete the task?", "Was workload tolerable for the task?", "Was workload satisfactory without reduction?"), the pilots start their decision making process in order to get to the appropriate section with the different workload descriptions and ratings. The workload descriptors are ordered with increasing levels and comprise ratings between 1 and 10.

Another unidimensional approach called video process rating to assess driver workload has been used by Totzke et al. (2008). They performed a driving experiment and recorded a video of the driving situation. At the end of the experiment, the driver had to watch the recorded video of the drive and was asked to continuously rate how the workload in the situation shown on the screen. This was done using a movable telltale and the current setting was assigned to the corresponding driving situation. Since the video-rating happens post-hoc, this approach has a temporary delay and may, therefore, reflect rather the perceived workload then the actual workload.

Multidimensional metrics comprise of various subscores to describe the demand on different dimensions of mental workload (Wickens and Tsang 2015). The NASA Taskload Index (NASA-TLX) (Hart and Stavenland 1988) is the most popular multidimensional approach to assess subjective workload. As already explained in Section 2.6.1 the NASA TLX uses questionnaires to assess the (subjective) workload for users–initially in the aviation domain–in six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration.

The Subjective Workload Assessment Technique is another questionnaire that divides mental workload into three areas (Reid, Eggemeier, and Shingledecker 1989; Reid and Nygren 1988; Reid, Shingledecker, et al. 1981): Time Load ("amount of time pressure experienced" (Reid, Eggemeier, and Shingledecker 1989) during a task), Mental Effort Load ("amount of attention and/or concentration required to perform a task" (ibid.)), and Psychological Stress Load ("presence of confusion, frustration, and/or anxiety which hinders completion of your task" (ibid.)). During experiments, for each task an event scoring takes place: A rating from 1 (low)

1. Time Load
   (a) Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.
   (b) Occasionally have spare time. Interruptions or overlap among activities occur frequently.
   (c) Almost never have spare time. Interruptions or overlap among activities are very frequently, or occur all the time
2. Mental Effort Load
   (a) Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.
   (b) Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.
   (c) Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.
3. Psychological Stress Load
   (a) Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.
   (b) Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
   (c) High to very intens stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Listing 4.1: Rating Scales of the Subjective Workload Assessment Technique. Scales extracted from Reid, Eggemeier, and Shingledecker (1989), Reid and Nygren (1988), and Reid, Shingledecker, et al. (1981).

to 3 (high) is given by the participants for each of the dimensions by using the rating scales as shown in Listing 4.1. Prior to the experiment, a scale development needs to be performed which makes the process rather time-consuming: 27 cards with all possible combinations of the levels of the three dimensions shall be sorted by the participant such that the rank order reflects the participant's perception of increasing workload. Conjoint measurement and scaling techniques are then used to convert the rank order into an interval scale from 0–100, providing a fixed value for each of the combinations on the interval scale.

Another very simple scale is the Rating Scale of Mental Effort, which constitutes a quick method to assess the subjectively felt effort of the driver (Zijlstra 1993). However, according to Miller (2001), it is only rarely used.

The NASA TLX questionnaire was adopted by Pauzie for the automotive domain known as the Driver Activity Load Index (Pauzié 2008). As explained in Section 2.6.1 this questionnaire considers the dimensions visual demand, auditory demand, tactile demand (sometimes skipped), temporal demand, effort of attention, interference, and situational stress. As outlined by Miller (2001) quite a large set of additional subjective methods has been investigated. However, most of them have not yet been applied or verified for multiple experiments or been used in the automotive domain.

While the methods and measures mentioned in the last sections can be helpful during experiments to evaluate driving situations and the performance of different tasks with automotive user interfaces, the focus of this chapters is on the continuous retrieval of driver workload information - also beyond experimental conditions. Since most subjective measures cannot be extracted automatically and without the driver's input, we will discuss and focus on other methods, mainly of physiological data. However, it is of interest to correlate both types of data.

Physiological Measures

In contrast to subjective metrics, physiological measures allow a continuous, unobtrusive sensing of the driver's bodily and physiological behavior. In this chapter, we employ such data to provide close to real-time and objective metrics that reflect onto the driver's workload. This can for instance be used as input for adaptive systems or "adaptive automation" (Wickens and Tsang 2015, p. 3) where frequent status updates of the driver's state are necessary to understand the driver and adapt the system to the driver's current state.

Looking at the available set of physiological measures, one can choose from various measurements that have been shown to be sensitive to the level of activation, to global arousal, or to specific stages in information processing (de Waard 1996, p. 37). Sensitivity relates in this case on the one hand to the "capability of the measure to discriminate among variations in mental workload" (Kramer 1990) and to the temporal aspect (ibid.). As outlined by de Waard (1996, p. 37), the advantage of such measurements is that they do not require an implicit input from a person and that they can be retrieved continuously. However, they also have some challenges and disadvantages. These include the technical expertise that is required as well as the influence of additional factors on the physiological signal (de Waard 1996; Kramer 1990). For instance, many bodily signals are influenced not only by mental workload but also by "physical exertion, emotional state, or ambient lighting" (Kramer 1990) that need to be considered during an evaluation.

Among the variety of physiological measures, the most prevalent ones are related to brain activity, cardiac functions, speech measures, eye activity, respiration, electrodermal and hormone level measures (de Waard 1996; Kramer 1990; Miller 2001). Kramer (1990) further classifies these into central nervous system measures and peripheral nervous system measures. The central nervous system in this case relates to the brain, the brain stem, and the spinal cord. Typical measures in this domain are EEG activity, event-related brain potentials, magnectic and metabolic activity of the brain, and electrooculography activity. As further outlined for instance by de Waard (1996) and Kramer (1990), the peripheral nervous system is further subdivided into the somatic nervous system (activation of voluntary muscles) and the autonomic nervous system which controls internal organs and muscles without voluntary control. The latter one is again separated into two systems: The parasympathetic nervous system is in charge of conserving and maintaining bodily resources while the sympathetic system's task is to react to stressful and emergency situations. Most organs influenced by both systems. Since the systems complement each other, can be reciprocally or independently active (Kramer 1990). As an example, Kramer (ibid.) explains that heart rate can increase due to decreased parasympathetic or increased sympathetic action. Eye activitiy, respiration, electrodermal and hormonal levels are measures of the autonomic nervous system. In the following sections, we will discuss a selection of these measurements, with a special focus on technologies that allow an unobtrusive measurement and that are expected to be well suited for the automotive environment.

Cardiac Measurements

Cardiac measurements are related to the contractions of the (human) heart that force the transmission of blood through the circulatory system (de Waard 1996): The heart muscles are controlled by both parasympathetic system and sympathetic nervous system. Their electrical impulses can be measured using electrocardiography, i.e., the recording of the heart's electrical activity by using electrodes that are placed on the human body. As further outlined by de Waard (ibid.), this allows to extract time domain, frequency, and amplitude measures.

Widely used measures for cardiac activities in relation to workload are heart rate and heart rate variability (de Waard 1996; Miller 2001; Solovey et al. 2014). Examining the ECG signal, it is possible to extract different electrical events that are related to the repeating activities of the heart muscles (Kramer 1990). As further described by Kramer, a typical procedure is to detect the R waves and use this to count the beats per minute (BPM) of the heart rate or the–for a single beat-reciprocally related inter-beat interval (measured in milliseconds). HRV then relates to the variability of the inter-beat interval and allows to extract various measurements in the time and frequency domain (de Waard 1996; Kramer 1990; Miller 2001).

The relation between (average) HR and (mental) workload has already been investigated thoroughly in multiple domains, including aviation and driving.

Roscoe (1993) found a strong correlation between HR and workload in studies with pilots. For instance, (Riener, Ferscha, and Aly 2009) measured the HR in a field study investigating the driver's arousal state indicating critical situations in which the driver should be aware of. Meshkati (1988) and Myrtek et al. (1996) report that a decreased HRV indicates increased workload.

Recently, different approaches were investigated to get rid of the need to attach electrodes to the user's body. Ford[3] proposed a system by using the car seat measure the HR. Poh, McDuff, and Picard (2010, 2011) and Wu et al. (2012) showed that the HR is observable using optical technologies, i.e. a video camera. This facilitates the retrieval of HR since such a technology does not required the user to wear electrodes any more. As an example for mass market capabilities, fist smartphone apps emply this technique to measure the heart rate by analyzing face videos[4].

Dermal Activities

Michaels (1962) showed that skin conductance response (SCR) is related to the amount of traffic the driver is facing at the moment. A direct relation to the workload was shown by Collet et al. (2003) in an experiment with air traffic controllers.

Mittelmann and Wolff (1939) found that there is a strong correlation between *skin temperature* and emotional stress. Or and Duffy (2007) used a thermal camera as a non-intrusive way to measure workload by observing the facial skin temperature.

[3] https://media.ford.com/content/fordmedia-mobile/feu/gb/en/news/2013/09/06/ford-president-and-ceo-alan-mulally-to-unveil-all-new-ford-s-max.html (last access: 2015-04-20)

[4] e.g., WhatsMyHeartrate, http://www.whatsmyheartrate.com/, last accessed: March 5, 2015

They showed a significant correlation between driver's workload and facial skin temperature through a driving simulator and field experiment. However, the work of Anzengruber and Riener (2012) indicates that thermal imaging does not yet work fully reliably to classify the driver's stress level.

Task-Evoked Pupillary Response

Eye gaze data has been established as an effective method for measuring mental workload in response to a cognitively demanding task, by focusing on certain parameters of autonomically-driven eye behavior. One strong advantage of using remote eye-trackers to estimate mental workload is that-–in contrast to many other physiological approaches–the user does not need to wear a specific device or sensor. Instead, a remote eye-tracker, i.e., one which is mounted next to a computer screen, can be used. Thus, measurements can be taken rather unobtrusively.

Pupils tend to dilate in response to greater mental workload (often called the "task-evoked pupillary response"). A number of early studies supported this relationship between pupillary changes and workload, and in a way established the foundation for this approach to psychophysiology (Kahneman and Beatty 1966; Kahneman, Onuska, and Wolman 1968). A dated but thorough review of the literature surrounding task-evoked pupillary responses outlined the relationship between changes in pupil size and mental workload (Beatty 1983). A key issue with using pupil diameter data to infer mental workload is that physiological changes in the eye are influenced both by lighting conditions and the difficulty of the task a person is engaged in. In creating algorithms to predict eye gaze changes based on mental workload, researchers have to parse out the effects of changes in lighting and mostly do so by choosing constant lighting conditions for experiments. A series of recent preliminary studies have addressed this issue in further detail, in the context of a simulated driving environment (Kun, Palinko, and Razumenić 2012; Palinko and Kun 2011, 2012). Methods have also been developed to gather eye gaze data in sub-optimal lighting conditions (e.g., Zhu, Fujimura, and Ji 2002). Furthermore, Marshall (2002) proposed the Index of Cognitive Activity, which attempts to estimate cognitive load independent of lighting, based on rapid pupil movement rather than on size. However, Marshall's proprietary algorithm by default outputs a sequence of estimates once a second, which can obscure interesting changes in cognitive activity that occur at a quicker pace, such as those observed in spoken interactions (Heeman et al. 2013; Kun, Palinko, Medenica, et al. 2013; Palinko, Kun, et al. 2010). Using the task-evoked pupillary response and compensating illumination should allow to detect such changes. However, this has not yet been done and tested for real-world driving situations.

To our knowledge, the study presented in this chapter is one the first study recording workload data with a comprehensive set of physiological sensors and context information in a real world driving study with at least 10 participants.

4.2 Real World Driving Study

As explained in Section 2.6 driver behavior may differ when comparing the behavior during a ride in a driving simulator to the one in a real car on an ordinary road. One reason is that the drivers always know that they only drive in a virtual world and may not suffer from (severe) accidents in a driving simulator. Thus assessing the drivers' workload only in a simulated environment is not sufficient for future systems. Therefore, we conducted a real world driving study consisting of a drive of about 30 minutes to collect realistic data. To also collect subjective feedback, a subsequent video rating session enabled us to collect subjective driver feedback as a kind of baseline measurement.

4.2.1 Apparatus and Data Collection

In order to collect realistic data, we conducted a study where we recorded different measures during a real drive around Stuttgart. Each participant used her/his own vehicle during the study. We recorded three different types of data during the driving session as also shown in Figure 4.2, namely physiological data, context information, and video data. As all data sets were recorded with different sampling frequencies timestamps were used to synchronize all data post-hoc. In order to facilitate data synchronization, we synchronized the clocks of the different recording components at the begin of each trial using the network time protocol.

In order to record the driver's physiological state, we attached three different sensors to each participant: Skin conductance and temperature sensors were attached to the participant's left hand whereas ECG electrodes were attached to the participant‘s chest. These sensors were connected to a Nexus 4 Biofeedback system[5] as a device to record the driver's physiological data.

We also collected certain context data during the ride. We did so by using a freely available Android app "sensor track"[6]) that we installed on a Google Nexus S

[5] http://www.mindmedia.info/CMS2014/en/products/systems/nexus-4, last access:2015-04-20

[6] https://play.google.com/store/apps/details?id=com.bushidroid.app.sensortrack, last access: 2015-10-20

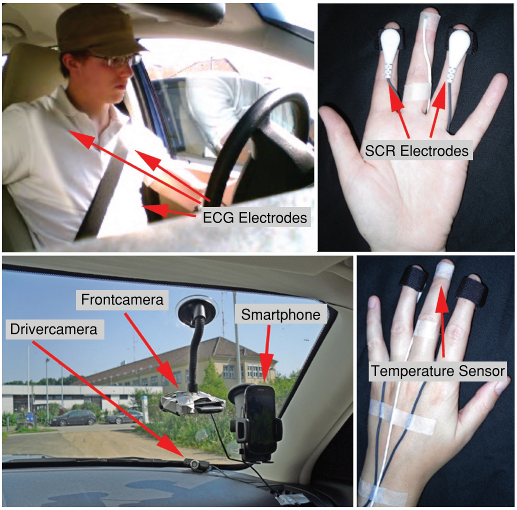


Figure 4.2: Apparatus for the real-world driving study: Two cameras and a smartphone are placed within the car (bottom left). Electrodes attached to the driver measure the ECG signal to extract heart rate and heart rate variability (top left). Skin conductance response (top right) and body temperature (bottom right) are measured at the drivers left hand.

phone. In particular, the Global Positioning System (GPS) position, brightness level, and acceleration were recorded. For the GPS position, the sampling rate was about 1 Hz, the other data was sampled at a rate between 8 Hz and 12 Hz.

As a third data type, two webcams (Logitech QuickCam Pro 9000 and Creative VF0610 Live! Cam Socialize HD) monitored and record the driving scenario (passenger view onto the road) and a view of the driver as shown in Figure 4.3. These cameras were connected to a Laptop that merged the live streams into one compound image that was then stored as a video file with annotated time stamps.

At the end of the ride, the video streams were played back to the participants in our lab. While doing so, they had the chance to rate the subjective workload that they experienced at each time of the video by adjusting a Phidgets[7] slider that was mounted in front of the computer screen. For this part of the experiment, we created a software that played back the recorded video, read the associated time stamp, and frame count for each image. This information was combined with the

[7] www.phidgets.com, last access: 2015-10-20

Figure 4.3: The route of the study can be divided into five different road types: 30 km/h zone, 50 km/h zone, highway, freeway, and tunnel. This figure shows the two perspectives recorded during the ride: The view of the driver camera is shown on the left side and the front view on the right side. This side by side composition video was shown to the participant during the video rating session.

current slider position as a representation of the perceived workload and stored into another file as an additional data set.

4.2.2 Participants and Procedure

Initially, we recruited twelve participants for our study. Since we used the first run as a test drive and had recording issues with another participant, the data of ten drivers was used for this experiment. Theses drivers (3 female, 7 male) were aged between 23 and 57 years ($M = 35.60$, $SD = 9.06$). We recruited them through e-mail and personal communication from employees of the University of Stuttgart in order to be covered by insurance. All of them owned a valid driver's license and brought their own car they were used to drive. Seven of the participants used their car each day, one participant 2–3 times a week, and two participants about 2-3 times a month. Regarding highway use, six participants stated to use the highway less than monthly, the others used it between 1–3 times a week.

On arrival at our lab, we welcomed the participants and explained the procedure of our study, including the types of data that will be recorded during the ride. To not influence the participants, we did, however, not state why this data will be recorded. As next step, the participants signed a consent form and we attached the physiological sensors to their bodies. This allowed to test the sensor placement and recording while the participants filled out the introductory questionnaire. Next, the participant's car was equipped with the different sensors by the experimenter. On completion of this task, we explained the planned route (see Figure 4.4) to the participant. During the ride, the researcher was seated at the back seat and provided simple voice instructions to the participant (e.g., "on the next intersection: please turn left"). At the end of the drive, the participant was asked to perform a *video rating* of his or her own ride at or lab in order to evaluate the perceived subjective workload. While watching the recorded video, the participant could rate the perceived workload from high to low using a slider as shown in Figure 4.5. The video shown was a side-by-side composition of the video streams that were recorded during the ride. Exemplary screenshots of these videos are shown in Figure 4.3. Overall, it took each participant about 110 minutes to take part in the experiment.

4.2.3 Route

Our pre-defined route for for the experiment has a total length of 23.6 km. It comprises various road types as shown on the map in Figure 4.4. For the evaluation, we distinguish between five different road types: 30 km/h zone, 50 km/h zone, highway, freeway, and tunnel. While the *tunnel* is an ordinary road, we decided to treat it as a special road type due to the particular conditions that may influence the driver (e.g., lighting). In addition, we have a look at some specific driving situations or points of interest: two on-ramp situations, two freeway exits, two roundabouts, 20 traffic lights, and two curvy road segments. Since we conducted a real world driving study, we were not able to control environmental factors such as traffic or weather. However, we strove for a consistent setting for all participants:

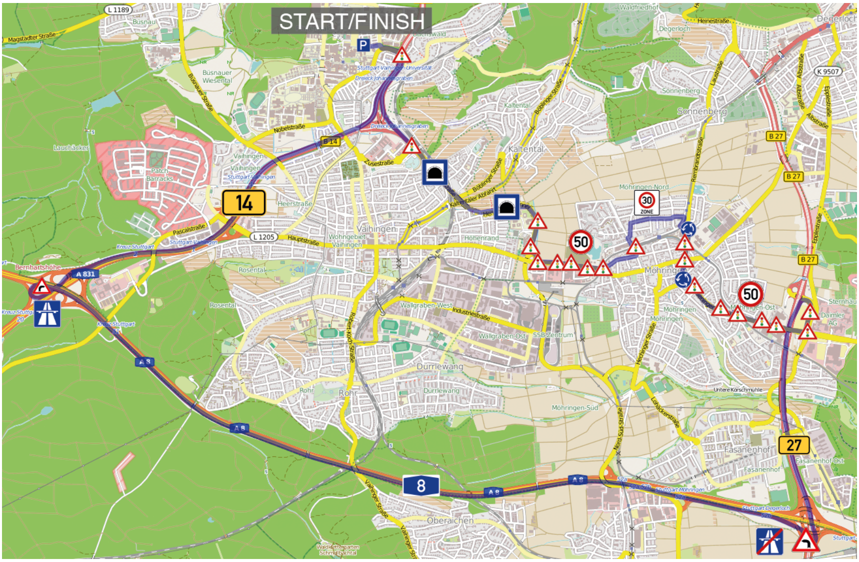


Figure 4.4: Map of the route each participant drove during the study. Each type of road is marked accordingly (A8: freeway, B14/B27: highway, ordinary streets (50 km/h), 30 km/h zone. All points of interest (freeway on-ramp/exit, roundabout, traffic lights, roundabouts, tunnel entry/exit) are shown with the respective symbols. Map ©OpenStreetMap contributors, tiles CC-BY-SA 2.0.

we avoided driving during rush hours and only selected time slots during the day (i.e., no driving without daylight).

4.2.4 Data Set

The data set we recorded is publicly available as an archive of comma separated files[8] where each file contains the merged data set of the recordings of one participant. The complete data set has a size of 450 MB and consists of 2.5 million samples. It is anonymized and contains information about GPS, brightness, acceleration, physiological data, and data of the video rating. Since the traffic conditions varied for each participant, the duration of the experiment runs differed between participants. This also is reflected by a varying number of samples per

8 The file can be found at: www.hcilab.org/automotive/

participant. In order to not reveal the identity of the participants, we excluded the video recordings from the public data set.

Beyond the initial analysis in this chapter, the data set may be used for different purposes. First, we believe that it is helpful for evaluations of novel concepts for automotive systems. Potentially, such evaluations can use the data set as a first step. This helps to save time since no own study needs to be performed. Additionally, we expect the dataset to be a first data point for an improvement of map databases. By annotating road segments with workload data, we to provide a novel parameter for navigation technology where driver workload is taken into account. Also, if such data in a larger scale, it may help to predict the workload of upcoming road segments, which can be used to adjust NDRA to this situation or even decide to adapt the level of driving automation. We published the data set since we believe that it has a value for researchers and practitioners. Even though we only cover a specific route around Stuttgart, we hope that it is a starting point for building a larger collection of data sets.

Physiological Data

In order to record physiological data of the drivers, we used different physiological sensors that we connected to the Nexus 4 physiological sensing system. As time-stamped recordings, we have the driver's electrocardiography (ECG), which is recorded in μV) at a frequency of 1024 Hz. Based on this data, we calculate the heart rate (HR) (in beats per minute, bpm) and heart rate variability (HRV) at 128 Hz. Beyond cardiac measurements we recorded the skin-conductance response (in μS) and body temperature (in $^{\circ}C$) at a frequency of 128 Hz.

Subjective Video Rating

For the post-hoc video rating we recorded a score between 0 (no workload) to 128 (maximum workload). The video rating is related to the current video frame that the participant saw at the moment of rating. Therefore the subjective ratings are tagged with the number of the particular video frame. This number is ascending, starting from 0 for each participant. The frequency of this rating is equivalent to the video frame rate of 29 Hz.

Position Details

During the experiment, we recorded the current GPS location using a smartphone at a frequency of 1 Hz.. In the data set the location is represented by samples for longitude and latitude (in degree) that define the position of the car. In addition to the location itself the dataset also contains details about the current altitude (in meter), speed (in meter/second), and bearing (in degree). For synchronization purposes, a timestamp allows to create a mapping between the different types of data.

Brightness and Acceleration

Since the smartphone also comprised sensors to measure brightness and acceleration, the dataset also comprises a measurement of the environmental brightness (in lumen) as well as the current acceleration of the car (three values that represent the acceleration in X-, Y-, and Z-direction relative to the phone). Both sensors have their own timestamps and are recorded at frequencies between 8 Hz and 12 Hz.

Data Extrapolation

The data is recorded at different sample rates. Hence, some data needs to be extrapolated to create a uniformed data set. We chose to extrapolate the data to the highest frequency keeping all available information of the sensor with the highest sample rate (ECG).

4.3 Analysis and Discussion

In the following we present the results of the study. At first, the correlation between the objective and subjective measures is investigated. Afterwards, the statistical differences between the road types are shown as well as the statistical differences between points of interest and road type.

4.3.1 Data Preparation

Before evaluating the recorded data, it needs to be prepared to remove noise effects as well as to normalize the physiological properties of each participant. We modified the data in several steps. At first, we sampled the data up to one sample per second, taking the mean of each value. We used the acceleration values to create a force vector. This vector is used rather than the force values for each dimension. Next, we normalized the physiological data as well as the video rating results to values in the range between 0 and 1 in order to achieve comparable values between all participants.

Figure 4.5: A participant is performing the post-hoc subjective video rating task. The participant watches a replay of his ride and continuously rates the perceived workload of the situation shown in the video.

In this evaluation we focus on two physiological values, skin conductance response (SCR) and body temperature (BTemp), as suggested by related work (e.g., Michaels 1962; Mittelmann and Wolff 1939), the results of the Video Rating (VR), and the actual driving speed.

4.3.2 Comparing Subjective and Objective Data

At first, we compared the subjective measurement (VR - cf. Figure 4.5) with the objective measurements (SCR and BTemp). Hence, we conducted correlational research comparing the VR to the physiological values using Pearson's correlation coefficient. The SCR and VR, $r(17725) = .202$, $p < .001$, as well as the BTemp and VR, $r(17725) = .128$, $p < .001$, are positively correlated. The correlations are both statistically significant, however, the effect size is small.

Looking at the data of individual participants, we find a high variability regarding the correlational patterns. For example, the data of participant #10 shows a high correlation between VR and SCR, $r(1903) = .689$, $p < .001$, and between VR and BTemp, $r(1903) = .449$, $p < .001$ as shown in Figure 4.6. In contrast, the data of participant #6 reveals a significant correlation between VR and BTemp,

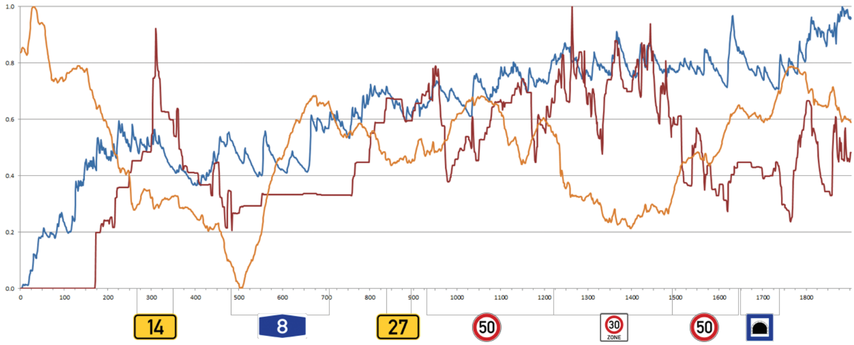


Figure 4.6: Comparison of the normalized Skin Conductance Response (blue), normalized Body Temperature (orange), and the normalized result from the Video Rating (red) of a single user (User #10).

$r(1710) = .072$, $p < .01$, but we did not find a statistical significant relation between VR and SCR, $r(1710) = .043$, $p = .078$. Thus, the data highly differs from driver to driver. This needs to be taken into account when using these values for assessing the workload.

4.3.3 Impact of Road Types

Looking at the characteristics of different road types, it is very likely that the driver's workload differs between different roads. Therefore, we wanted to see how the physiological data and the subjective ratings differed between the five road types of our experiment. Since the values highly depend on each other and since the different road types are not equally distributed within our sample (cf., Figure 4.6), we chose to use the mean values of each participant on each type of road. Thus, we eliminate most of the dependencies in the data and create an equal distribution.

The results show that the physiological data (SCR and BTemp), and hence the workload, are influenced by the road type. As shown in Figure 4.7, the variance in the data is high, which indicates that all types of roads have situations in which the workload is high for some participants. In order to investigate statistically significant differences between the five road types, we used a repeated measures analysis of variances (ANOVA). A Shapiro-Wilk test shows for all cases that the assumption of normal distribution is not violated.

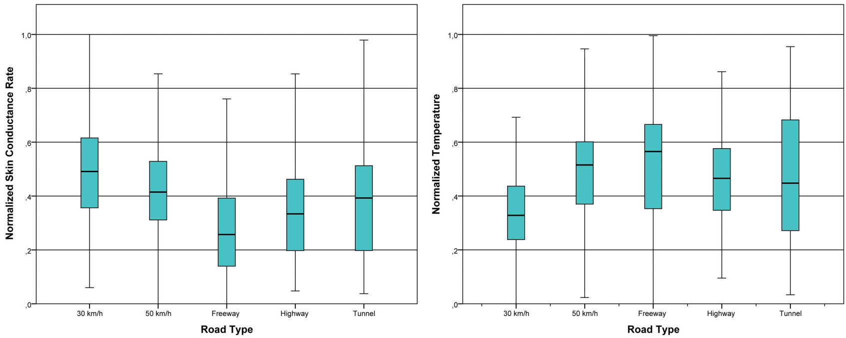


Figure 4.7: These boxplot diagrams show the Skin Conductance Response and Body Temperature for each of the five road types.

Table 4.1: Overview of the mean and standard deviation of the normalized skin conductance response (SCR) and body temperature (BTemp) on the different road types.

Road Type	M_{SCR}	SD_{SCR}	M_{BTemp}	SD_{BTemp}
30 km/h zone	.482	.178	.357	.152
50 km/h zone	.423	.152	.484	.137
Highway	.343	.110	.487	.156
Freeway	.271	.121	.522	.155
Tunnel	.394	.223	.468	.266

Skin Conductance Response As also shown in Table 4.1, SCR is lowest for the freeway and highest for the 30 km/h zone. Mauchly's test indicates that the assumption of sphericity had been violated, $\chi^2(9) = 17.890$, $p = .041$, therefore, degrees of freedom were corrected using Greenhouse-Geisser estimation of sphericity, $\varepsilon = .529$. The ANOVA reveals statistically significant differences within the five road types, $F(2.116, 19.042) = 6.756$, $p < .05$, $\eta^2 = .429$. A Least Significant Difference (LSD) post-hoc test reveals a statistically difference between all road types, $p < .05$, except for Tunnel with 50 km/h zone, $p < .438$, and highway, $p < .439$. This can be explained by the fact that the Tunnel in our route is part of a highway with a speed limit of 50 km/h.

Body Temperature The BTemp is lowest for the 30 km/h and highest for the freeway (cf. Table 4.1) indicating that the workload is highest for the 30 km/h zone and lowest for the freeway. Again, Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(9) = 27.069$, $p = .002$, therefore, we corrected the degrees of freedom using Greenhouse-Geisser estimation of sphericity, $\varepsilon = .357$. After the correction, the ANOVA does not reveal statistically significant differences within the road types $F(1.427, 12.842) = 1.305$, $p = .292$, $\eta^2 = .127$. Even with the ANOVA not revealing significant results, the data indicates that at least the 30 km/h zone is different from the other road types (see also Figure 4.7).

Driving Speed On all five road types, the speed limit is different. Furthermore, the driving situation (e.g., traffic, weather) has an influence on driving speed. Again, Mauchly's test is significant. Hence, the assumption of sphericity had been violated, $\chi^2(9) = 37.846$, $p = .000$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimation of sphericity, $\varepsilon = .407$. Nevertheless, the ANOVA shows statistically significant results, $F(1.628, 14.649) = 444.505$, $p < .05$. A Least Significant Difference (LSD) post-hoc test reveals a statistically difference between all road types, $p < .05$, except for highway with freeway, $p < .728$, because both road types have similar amount of traffic and roughly the same speed limits.

Video Rating In the Video Rating session, the participant rated the highway as the road with the lowest workload and the 30 km/h zone as the one with highest workload (see also Table 4.1). The assumption of sphericity had been violated, shown by Mauchly's test of sphericity, $\chi^2(9) = 20.589$, $p = .017$, thus, degrees of freedom were corrected using Greenhouse-Geisser estimation of sphericity, $\varepsilon = .601$. Between the road types, the ANOVA does not reveal any statistically significant difference, $F(2.405, 21.647) = 1.249$, $p = .312$, $\eta^2 = .122$. Again, the highest difference is between the 30 km/h zone and the other road types.

Discussion Interpreting the physiological data, we see that the road type influences the driver's workload. Especially the 30 km/h zone seems to challenge the driver (low BTemp and high SCR and VR indicate an increased workload). This may be related to spots in which the driver has to reason about the right of way which might increase the workload. In addition, such areas typically have many parked cars which serve as sources for unexpected events like pedestrians crossing the street, playing children, or car doors that are carelessly opened. In contrast, the freeway seems less demanding and in consequence shows physiological responses that are related to a lower workload (high BTemp and low SCR). We relate this to the fact that the freeway driving situation is rather predictable and does not need that much attention due to larger distances between the cars. These results match the results from Michaels (1962) as well as from Mittelmann and Wolff (1939).

4.3.4 Points of Interest

As explained before, we identified five different points of interest (POIs) which create interesting and potentially challenging situations to the driver: highway on-ramps, highway exits, roundabouts, traffic lights, and very curvy road segments. In this evaluation we have a specific focus on the freeway on-ramp and exit situations. Hence, we compare the SCR, BTemp, and VR of these POI with the average of the freeway by using a series of t-tests.

The SCR increases at both types of POIs (on-ramp: $M = .409$, $SD = .095$; exit: $M = .328$, $SD = .152$) in comparison to the average of the freeway ($M = .271$, $SD = .122$). Using a paired-samples t-test we found that the difference between on-ramp and freeway is statistically significant, $t(9) = -3.546$, $p < .05$. However, we could not find a statistically significant difference between exit and freeway situations, $t(9) = -1.624$, $p > .05$.

For the body temperature we see a reduced BTemp on the on-ramp ($M = .437$, $SD = .210$) compared to the average of the freeway ($M = .522$, $SD = .155$). However, BTemp increases on freeway exits ($M = .561$, $SD = .145$). Again, a dependent t-test does not reveal a statistically significant difference when comparing the average BTemp on the freeway with on-ramp situations, $t(9) = 1.668$, $p > .05$, and exits, $t(9) = -1.176$, $p > .05$.

In addition to the objective methods described above, the subjective video rating shows similar results. Both, on-ramp ($M = .463$, $SD = .285$) and exit ($M = .384$, $SD = .239$) situations show an increased subjective workload compared to the average freeway ($M = .302$, $SD = .171$). A dependent t-test shows statistically significant differences for the on-ramp, $t(9) = -2.643$, $p < .05$, but no difference for the exit, $t(9) = -1.895$, $p > .05$.

Summing these results up, the objective as well as the subjective methods indicate that the POI result in a different workload compared to the average freeway. Especially the on-ramp situation shows statistically significant increased driver workload.

4.3.5 Discussion and Limitations

The data set provides details on how physiological data as well as subjective driver ratings are related. The results from our first evaluation show significantly different physiological values for different road types and we show a correlation between video rating and the physiological values. Analyzing the data reveals that it is important for physiological data to cater for participants' individual data. Thus, it is important to normalize such data in order to be abstract from a single user. In our presented evaluation this helped to generate comparable measurements.

We are aware that the design of the experiment lead to a number of limitations. One aspect is related to nervousness which can influence physiological data. Since we used the recordings directly from starting the car until the end of the experiment, this may have affected especially the beginning of each run. However, we expect this effect to be rather low as we tried to create a comfortable environment during the experiment, for instance using the participants' own cars.

Due to the selected route, the number and types of streets is limited in this data set. We are aware that the data set does not cover every type of road and situation. However, by carefully selecting the route, we were able to assemble a representative set of streets for typical roads found in Western Europe.

In order to establish physiological measures as a way to infer driver workload, we see various remaining challenges. First of all, technology needs to be advanced to increase the reliability and robustness of sensor measurements. Similarly, it is required to build upon less intrusive technology such as video-based HR detection in order to increase usability and user acceptance. As discussed in the related work section, an alternative to estimate the driver's workload could be to use eye-tracking in order to infer the driver's pupil diameter and based on this the task-evoked pupillary response. For this technology, the challenge is to cope with different illumination situations (e.g., sunlight vs. roads at night). In a recent experiment (Pfleging, Fekety, et al. 2016), we presented a proof-of-concept model that distinguishes different (but fixed) illumination situations. However, additional experiments are necessary to transfer this to real-world scenarios.

In the experiment, we attached different sensors to the participants' bodies in order to retrieve physiological information. We agree that this is only acceptable for experimental setups but not for future real-world use. However, outside of experimental evaluations we expect that such information can easily be retrieved as implicit input with less invasive technology that the user does not have to put on before starting the car in the near future. Such technology is currently under development and partly already integrated into products. It includes for instance sensors integrated to the steering wheel (Gómez-Clapers and Casanella 2012; Lin et al. 2007) or wearable sensors[9] and smart clothing (Axisa et al. 2005) which will enable an unobtrusive integration of such technology in future cars.

As a most important step, models need to be found that allow for an adaption to the driver's individual physiological characteristics in order to allow systems to infer workload details based on raw physiological data.

4.4 Summary

In this chapter we discussed workload as one important part of the driver's state. In a real world driving-study we collected physiological data as well as additional context information, and post-hoc one-dimensional subjective workload ratings. The recordings of the study have been published as a data set in order to enable researchers and developers as a basis for their work on automotive user interfaces that take the driver's workload and context information into account. The data set comprises about 2,500,000 samples taken during the experiment that we conducted with 10 participants during a ride of about 30 minutes. We assume that the data set can be helpful in a variety of situations during the design, development, and testing of future systems.

The driver workload, as one component of the driver's state, is one important aspect for future user interfaces that support NDRAs and highly or fully automated driving. Understanding the driver state can help to adapt NDRAs in order to match the driver's state and prevent overload or underload. In particular, this will be important when automation levels is expected to change during a ride since the vehicle systems need to detect whether the driver is able to take over control again. Another example is the situation of partly automated driving where the driver workload may be one important detail that affects the selection of NDRAs that can be offered to the driver to keep performance and distraction at acceptable levels. For the concept of sharing context information with remote callers that will be explained in Chapter 6, details about the driver workload can be helpful as well, since these might provide clear hints to the remote caller whether contacting the driver in the vehicle is appropriate or not.

---

9 see for instance http://www.polar.com/en/about_polar/press_room/press_releases/integrated_training_system, last access: 2015-10-20

In order to get a detailed view of the driver state, different aspects need to be considered as outlined by Reimer, Coughlin, and Mehler (2009). Especially for take-over-requests between highly automated driving and lower levels of automation, vehicle systems need to get access to a multitude of facts about the driver. Thus, future systems should provide means to allow detailed monitoring of the car interior, including details such as the seat position and physical movements of the driver as well.

Chapter 5

Facilitating Enjoyable Interaction:

Multimodal Input to the Car

In modern cars, we see a multitude of controls for various systems of the vehicle. Being most important for the (manual) driving task, we still find the traditional controls to safely maneuver the car such as steering wheel, gear shift, pedals, windshield wipers, lamps, and indicators. However, today cars offer many additional functions related to safety (for example driving assistance), comfort (for instance power windows, air conditioning), communication (for example hands-free calling, SMS reading), productivity and entertainment, i.e. secondary and tertiary (or non-driving-related) tasks (Kern and Pfleging 2013). Prominent functions that have been added over the last decade include navigation features and access to location-based information such as the next gas station or traffic information, a variety of entertainment features including the interaction with large music collections, playing (web) radios, or selecting an online music service, as well as the control of assistance systems such as ACC, parking assistants, and night vision.

We see multiple reasons for this development. Many of these inventions and features have been integrated to either increase driving safety or to improve driving comfort. Both factors allow to distinguish different cars and brands, and thus enable unique selling points. In addition to pure safety and comfort improvements, we also see the trend of adapting the car to changes in everyday life. This includes in particular the growing demand for mobile connectivity in general and especially the Internet. Being available on a mobile or smart phone through voice calls or text messages and having access to the Internet is expected in at any place and time (Árnason et al. 2014; Sohn et al. 2008). This also holds for the car where we see an increased demand to interact with such devices and services on the go—either through an IVIS in the car or by directly using a personal mobile device. During the last years, many highlights of new vehicles were not shown at car trade shows but at trades shows that are related to consumer electronics and entertainment. This highlights the importance of connectivity and entertainment features in the car. For instance, by observing events like the Consumer Electronics Show one can get the impression that the car is presented rather as an intelligent gadget on wheels and a mobile terminal[1]. One observable trend is that in-car interfaces try to catch up with other consumer technologies such as smartphones and tablets with respect to interaction, available features, and user experience. We expect this trend to even increase with the availability of automated driving since this will for the first time officially release the driver from the obligations to steer and monitor the car. Especially commuters aim at utilizing the time to and from work for (social) interaction and communication.

Until we get to the point where fully automated driving is available, the need for communication and entertainment however conflicts with the primary driving task. As outlined before, guidelines and legislation limit additional activities in the car in order to avoid distraction of the driver but instead to maintain and increase driving safety. This includes the requirement that the interface should not be entertaining but also simple and easy to use (AAM Driver Focus-Telematics Working Group 2006; ESoP 2007; JAMA 2004). However, even with hand-held mobile phones being legally banned while driving in many countries we see that drivers use or want to use them on the road.

With each added function or system the car cockpit becomes more complex. Buttons and other manual controls such as dials, sliders, and levers still play a very important role in the automotive design space (Kern and Schmidt 2009). One significant advantage of most of the physical controls that they can be used eyes-free, just by feeling and perceiving the haptic feedback (Kern and Pfleging

[1] see for instance http://www.bloombergview.com/articles/2015-01-07/the-most-important-auto-show-is-now-at-ces, last access: 2015-06-20

2013). This allows the driver to keep the eyes on the road. However, given the large number of available functions, the traditional approach to add a control for each function does not scale as the space within the driver's reach is limited. It is apparent that such a one-to-one mapping between controls and functions is not possible any more (Kern and Pfleging 2013; Zeller, Wagner, and Spreng 2001). Otherwise, the car interfaces could become as complex as the cockpit of an aircraft that is only usable by highly trained experts. Also, this would mean that not each control could be within hand's reach and that the driver cannot remember the location of each control (Kern and Pfleging 2013) or perform eyes-free interaction.

In this chapter we propose a temporally cascaded, multimodal interaction style as an alternative approach to access a multitude of functions. We combine speech and gesture in the following way: First, voice commands are used to select objects (mirror, window, etc.) or functions that should be manipulated; second, simple touch gestures are used to control these functions. With this approach recalling voice commands is done with little effort as the users just need to provide the object or function of interest. This applies in particular to objects the driver can see , since (he) can establish a cognitive mapping between object (image) and name. By performing a simple touch gesture anywhere on the steering wheel, the interaction style lowers the visual demand and provides at the same time immediate feedback and easy means for undoing actions in comparison to pure speech interaction. To design the system, we first conducted a formative study on user-elicited speech and gesture commands. Based on these results, we implemented a functional prototype that allows evaluating the suggested interaction style.

The goal of the approach that we propose in this chapter is to offer an alternative for controlling in-vehicle functions with low driver distraction but in an enjoyable way. Minimizing visual distraction and reducing drivers' workload are central design goals. In our research we suggest to revisit the idea of multimodal interaction as it provides a great benefit over systems operating on a single modality. Since the visionary work of Bolt (1980), different research projects have investigated on multimodality and general guidelines have been shaped (e.g., Reeves et al. 2004). However, no specific usage pattern or interaction style for an integration of different modalities has been widely adopted in the car by now.

The contributions of this chapter are (1) a set of basic gestures and voice commands for in-car interaction, (2) an investigation for which functions multimodal interaction using speech and gestures is appropriate, (3) a description of our prototypical implementation, and (4) an evaluation of the proposed interaction style in a driving simulator.

This chapter is based on the following publications:

- Bastian Pfleging, Stefan Schneegass, and Albrecht Schmidt (2012). Multimodal Interaction in the Car: Combining Speech and Gestures on the Steering Wheel. In: *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '12. Portsmouth, NH, USA). ACM: New York, NY, USA, pp. 155–162. ISBN: 978-1-4503-1751-1. DOI: 10.1145/2390256.2390282
- Bastian Pfleging, Tanja Döring, Michael Kienast, and Albrecht Schmidt (2011). SpeeT: A Multimodal Interaction Style Combining Speech and Touch Interaction in Automotive Environments. In: *Adjunct Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria), pp. 65–66. URL: http://www.auto-ui.org/11/docs/AUI2011_adjunctproceedings.pdf#page=65

5.1 Related Work

As outlined already in Section 2.2, one can observe extensive research in the domain of automotive user interfaces. The common goal is to find enabling interaction with the driving tasks and NDRAs and to minimize driver distraction at the same time. We used the design space by Kern and Schmidt (2009) to assess trends in automotive UIs. Our assessment showed that there is a trend towards adding more controls to the steering wheel. The rationale is simple since physical controls that are added to the steering wheel are in easy reach for the driver and do not require her or him to take the hands off the wheel. However, looking at the resulting design space, it is apparent that this trend is limited by the number of buttons and controls that can be added into this area. This motivated the use of the steering wheel as input space, but in contrast to the recent trend of adding physical buttons, we chose to explore touch input as an alternative modality to overcome this mapping conflict.

Today, designers carefully have to decide which controls to make directly accessible via a physical control. The remaining functions and features then require a more complex interaction procedure. The introduction of display technology in the car thus led to a central multi-functional system. Many of those in-vehicle infotainment systems rely on a central information display and a controller or touch input to operate the hierarchically organized system and access different functions. Only the essential or favorite functions can be accessed via dedicated buttons. Thus, to access a certain function, the driver often needs to navigate through the different menus. Important drawbacks of an interaction with these systems are that the driver's visual attention is needed. Moreover, some features might not even be found by the user. Also, the time to execute a certain function can be much longer than operating a physical control, and the operation impacts driving performance and (subjective) workload (Mitsopoulos-Rubens, Trotter, and Lenné 2011). Assessing the design space beyond menus, knobs, and buttons, several input modalities present potential alternatives for in-car interaction that we discuss in this section: (1) speech interaction, (2) midair and (3) touch gestures, and (4) gaze interaction.

5.1.1 Speech Interaction

Since driver's visual attention to the road is most important for the primary driving task, one approach of overcoming the mapping conflict and the drawbacks of visual IVIS is the *use of speech for input and output* or even a multimodal approach that allows different ways of input and output. As for instance summarized by Barón and Green (2006) and Peissner, Doebler, and Metze (2011), voice interaction has been shown to improve driving performance, to reduce subjective workload, and to reduce the eyes-off-the road time. At the same time, Peissner, Doebler, and Metze (2011) highlight that remaining issues for such interfaces are interaction complexity, recognition accuracy, and the need for sequential input and output via speech while graphical interfaces allow for parallel feedback. Also, undoing actions may take longer than with physical controls. However, voice interaction is beneficial since it may offer shortcuts or allow the driver to just mention the intended action instead of navigating through various menus (ibid.). Maciej and Vollrath (2009) also identified the potential of speech-based interaction in the car. They observed improved driving performance, gaze behavior, and less subjective distraction using speech in various situations. While they further outline that current technology still does not reach baseline level (i.e., only driving), they see speech interaction as a must-have technology for future cars.

Speech interaction is already widely implemented for selected functions, e.g., for navigation destination input or to initiate a phone call. It has been investigated for in-car interaction for years, and many efforts focus on the improvement of recognition accuracy of speech input (Winter, Grost, and Tsimhoni 2010). Nevertheless, so far only a minority of drivers regularly uses speech input due to various reasons. One challenge is the acceptance of such systems and–related to this– the effort for learning and remembering specific voice commands (Pickering, K. Burnham, and M. Richardson 2007). During a panel discussion at the AutomotiveUI conference 2011 in Salzburg (Austria) with a technology-savvy audience of researchers, the question who uses regularly voice interfaces in the car confirmed this (with a non-representative sample of about 100 attendees of whom less than 5 people were regular users–including speech interface researchers).

With an increasing number of functions this problem becomes more important as the hurdle for taking up speech as a modality is even increased. Beside some remaining technical difficulties, the lack of conceptual clarity is still a problem. The latter is nowadays alleviated with natural voice user interfaces (Alvarez et al. 2011) but systems still suffer from a user experience point of view (Wärnestål and Kronlid 2014). For instance, approaches have limitations with regard to immediate feedback and visibility of commands. The perceived user experience (UX) is another crucial aspect, in particular for speech UIs. This issue is investigated for in-car speech input by Goulati and Szostak (2011). Hua and Ng (2010) review speech-related automotive projects and provide guidelines for future voice-activated systems. They recommend that speech interfaces should use a shallow hierarchy, provide visual feedback, memory aids, and vocal shortcuts. In line with other research, they recommend that frequently used tasks should be available through direct controls (e.g., buttons on the center stack or steering wheel). Based on the previous findings we designed a multimodal approach combining gesture and speech with a focus on UX.

5.1.2 Midair and Touch Gestures

Touch input is a commonly used modality in the car, either by using touch screens (see for instance Pickering, K. Burnham, and M. Richardson 2007) or touch-sensitive controls (touch pads). The latter can be found at different locations, including the steering wheel (González et al. 2007) as well as other locations such as the push-and-turn controller (Johanning and Mildner 2015) or a dedicated touch pad on the center stack (e.g., Johanning and Mildner 2015; Vilimek and Zimmer 2007). Spies et al. (2011) investigated a haptic touchpad as a mean for controlling in-car UIs. In this approach visual attention is required.

Another alternative is the use of gestures (Akyol et al. 2000) in the car. Various examples for such interfaces exist, including (midair) hand gestures (Pickering,

K. J. Burnham, and M. J. Richardson 2007; Zobl, Geiger, Bengler, et al. 2001; Zobl, Geiger, Schuller, et al. 2003), finger gestures (Riener and Wintersberger 2011), touch gestures (Bach et al. 2008; Ecker et al. 2009) that form an extension of touch input on touch pads and touch screens, and pressure-sensitive gestures on the steering wheel (Angelini et al. 2013). Using midair or touch gestures poses a similar learning issue as command-based speech interaction. Here, too, users have to remember the functions they can operate along with the related gesture (Long, Landay, and Rowe 1999). Also, with regard to the agreement which gesture to use for which function, certain difficulties arise (Pickering, K. Burnham, and M. Richardson 2007; Ruiz, Li, and Lank 2011; Wobbrock, Morris, and Wilson 2009). This is in contrast to visible representations on a screen that can also be manipulated and explored by touch. There, it is not necessary to remember commands; instead, visual attention is required. In order to reduce the number of eye glances for NDRAs, the work by Bach et al. (2008) indicates that touch gestures may be one feasible approach.

Döring et al. (2011) used gestures of a multi-touch steering wheel for a gesture based interaction style with different applications, such as navigation or a music player. In their work a gesture set was created in a user-centered design process. The comparison of the gesture set with classical means for interacting with an infotainment system showed that using gestures reduces the visual demand for interaction tasks. However, the use of gestures introduces a similar problem as buttons: scalability. By using touch gestures that do not need visual attention, the gesture rapidly becomes complex and hard to remember. When using touch interaction that relates to the displayed content on the screen, the benefit of reduced visual attention is lost. This motivated us to investigate gestures further, as one modality in a multimodal UI.

5.1.3 Gaze Interaction

In order to lower workload and driver distraction, different input modalities are being evaluated. Gaze and body posture are two examples of implicit modalities that can be used to provide more natural forms of interaction that have the potential to reduce cognitive load. Gaze interaction was explored for instance by Kern, Mahr, et al. (2010) and Kern, Marshall, and Schmidt (2010). In the latter project, the last fixation of the user before switching attention from the in-car screen to the real world was detected. This fixation was then used to highlight an area on the screen and by these means ease the attention switch from the road to the display. We expect that in a future version of our system a similar concept could be used to detect which items people look at and use this as further modality to disambiguate commands. Similarly, body posture (e.g., head position) could be used to detect the objects towards which the user's commands are aimed at.

5.1.4 Multimodal Interaction

As defined by Oviatt (2012) multimodal systems are "those that process two or more combined user input modes–such as speech, pen, touch, manual gestures, gaze, and head and body movements–in a coordinated manner with multimedia system output". Thus, for multimodal interaction the user can either select between alternative interaction modalities or use multiple of them in a combined method. Müller and Weinberg (2011) elaborate on the definition of multimodal interaction in the car. They describe three methods for combining different modalities: fused modalities, temporally cascaded modalities, and redundant modalities.

An example for fused modalities is given by the "put-that-there" approach by Bolt (1980): pointing gestures were used accompanied with speech input containing deictic references like "that" or "there". This idea has been particularly applied for 2D map interactions (e.g. Sharma et al. 2003). Pointing at real objects in the 3D space of a car is, however, more difficult and several functions cannot be associated with a physical location in the car. To avoid these problems, for our approach we swapped the modalities of speech and gesture. We implemented an example temporally cascaded modalities as proposed by Müller and Weinberg (2011): first, using speech to select a real object and one of its functions and, second, offering touch gestures to specify parameters. A similar approach combining speech and other modalities in cars has been made in industry and in research (Endres, Schwartz, and Müller 2011; Müller and Weinberg 2011) where a concept of combining freehand gestures and speech input for making phone calls was presented. In contrast, our approach aims at a general interaction style that covers many functions and goes well beyond a single application control.

5.2 Concept: Combine Speech and Gestures

The major design goal of our approach and user interface is to ensure a good usability in the context of usage in the car. We therefore examined common usability guidelines that are traditionally targeted at desktop systems (e.g., Molich and Nielsen 1990; Shneiderman et al. 2009) and identified several drawbacks of current unimodal approaches and designs. The proposed multimodal interaction style addresses these shortcomings. We first describe challenges of existing approaches that we focused on before we explain our interaction style.

5.2.1 Challenges of Current Solutions

Learnability Current implementations of command-based speech interaction techniques require the user to learn and remember commands in order to achieve a satisfactory user experience. Natural voice user interfaces (e.g., Dragon Drive[2]) have been created to tackle the problem of remembering by allowing a wide range of natural commands. However, the driver needs to know the capabilities of the car that can be controlled by voice. In case of ambiguity such systems require an additional clarification of commands (Alvarez et al. 2011), which makes the interaction more cumbersome. Also, inconsistent command sets can confuse the driver and reduce learnability (Müller and Weinberg 2011).

Touch interaction or gestures as a single modality have a similar disadvantage. They require the user to remember a potentially large number of gestures (e.g., one for each command) that can be differentiated by user and system, or they increase the complexity of gesture sequences. Regarding the expressiveness of gestures, studies have shown that it is hard to remember a large number of commands in the form of complex gestures (Long, Landay, and Rowe 1999). Such a large number needs to be covered in environments with a multitude of functionalities such as infotainment and entertainment systems in cars.

Design Goal 1: *Minimize the effort for learning and remembering.*

Visibility In contrast to visual menus, current speech interfaces as well as gestural interface often do not visualize command options. A good interface design is created that it respects the *visibility principle* (Molich and Nielsen 1990) and offers means for the users to visually perceive choices without having to remember. Users should see the options they have to do a task, but the design should reduce distraction by hiding *unnecessary alternatives*. For speech interfaces, it is difficult to serve this principle by means of visualizing the available interaction grammar or commands. Additionally, providing meaningful feedback for every operator action is *time-consuming* and maybe even annoying - especially if the feedback should be non-visual

[2] Nuance - http://www.nuance.com/for-business/mobile-solutions/dragon-drive/, last access: 2015-05-02

in order to keep a low visual distraction. It is similarly difficult for gestural interaction to provide visibility of interaction possibilities as for speech.

Design Goal 2: *Create an interaction style that maximizes the visibility of command options in the car.*

Granularity Using sliders or gestures, interaction can be very fine-grained. For speech interaction, the granularity of a single interaction is low and the "Achilles heel of speech-based interaction" (Müller and Weinberg 2011). As speech commands take a certain while to be spoken (in general longer than a button press or a simple finger movement) the granularity of the provided interaction primitives is usually designed bigger in order to not increase the overall interaction time. Although combining basic commands like "move window up", "repeat", and "stop window" is possible, it is questionable if a precise window control can be realized due to delays between the user saying a command, parsing the command by the system, and perceiving a system response (i.e., window movement).

Design Goal 3: *Provide fine-grained opportunities for interaction.*

Undo Modern UIs in the desktop domain have massively benefited from means to revert/undo actions taken. This helps users to explore systems without too much worrying that something goes wrong. Similarly, in the car an easy undo of actions is essential as even small errors may be distracting and time-consuming to be corrected, e.g., by giving a fully formed sentence. A potential command might be: "Close the driver's window by 80 %.". If the driver notices after the execution that the window had been moved too far, another command has to be said to partially or completely undo the last action and to achieve the goal.

Design Goal 4: *Support means for simple partially or completely undo of actions.*

Consistency When interacting with a system words, situations, actions, shortcuts and other concepts should be chosen consistently such that the user does not need to wonder whether two concpets mean the same thing (Molich and Nielsen 1990). In current systems, this rule is often broken (Müller and Weinberg 2011). As one example, Müller and Weinberg (ibid.) describe that for IVISs often the interaction sequences for speech and manual input differ regarding the procedure. This makes it difficult to (1) switch between different modalities or (2) remember the correct interaction sequence. To facilitate interaction and reduce cognitive workload, such situations should be prevented.

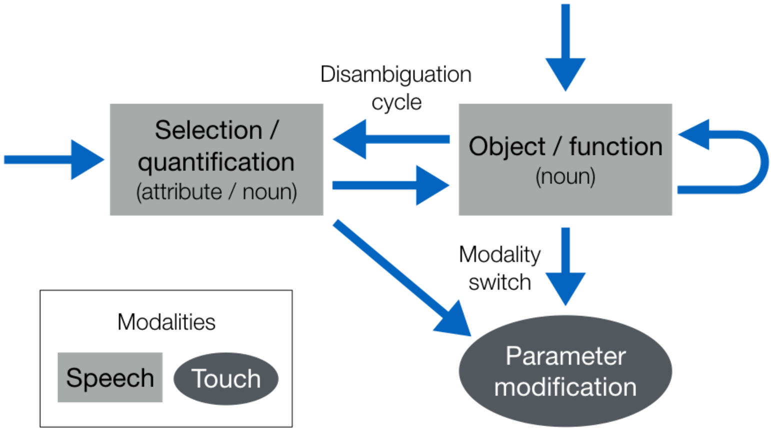


Figure 5.1: Scheme of the speech-gesture interaction style: Interaction objects and functions are selected using speech commands. Touch gesture allow as a second step to adjust the object or function.

Design Goal 5: *Create consistent user interfaces.*

These five design goals are difficult to realize using a single interaction technique. Simple (single stroke) touch and pointing gestures are well suited to realize design goal 1, 3, and 4. For example, they allow a fine-grained granularity of interaction and provide means to easily undo an action (e.g., by doing the reverse gesture/movement).

5.2.2 Interaction Style

Our multimodal interaction style addresses the previously described challenges and helps to achieve the postulated design goals. In its first version, this multimodal interaction style combines especially speech and gesture interaction as it is presented in Figure 5.1. Additional modalities such as gaze interaction can be integrated to support the interaction.

Selection / Quantification

As a first step, the driver uses speech commands to select and qualify one or multiple objects or features (e.g., “window") to be manipulated and their function (e.g., “open"). In order to prevent unintended interactions, the speech recognition is either started by first pressing a dedicated button (e.g., on the steering wheel) or by uttering a specific command that is rather unlikely to be part of typical conversations in the car (e.g., the word “command” itself).

If an object offers only one function that can be manipulated, the selection process can be as short as just saying the name of this object and implicitly choosing its function, e.g., “cruise control". If multiple instances of an object or a class of objects exist (e.g., windows), the desired objects need to be qualified appropriately (e.g., “passenger window", “backseat windows", “all windows”, “ventilation passenger - intensity”). The interaction can also be started by just saying the (unqualified) name of the object (“window"). Objects that offer more than one function require the user to also clearly select the function. If the selection is ambiguous, the system will provide immediate auditive feedback (a “negative” beep sound and a spoken explanation) and ask for a suitable quantification until the object and function selections are unambiguous. If multiple functions or parameters to manipulate exist for the selected object, an auditive feedback notifies the driver about this fact. The *disambiguation cycle* as presented in Figure 5.1 assures an explicit selection of object(s) and function by providing speech prompts to refine the selection. As soon as object/feature and function have been selected unambiguously, a confirming beep informs the driver. Additionally, the selected operation is repeated by the system to confirm the recognition. Now, the modality switch from speech interaction to touch gestures (on the steering wheel) takes place in order to perform the intended manipulation.

Depending on the context, the speech prompt can also be combined with a visual presentation of options (e.g., on the head-up display, the central information display, or the steering wheel display) to qualify the object or function. For instance, when object or function have not been selected unambiguously, the available options can be presented through speech / and or a list that is visualized on on of the available displays. Additionally, the selection and disambiguation could be supported by observing the user’s gaze, similar to the idea mentioned by Müller and Weinberg (2011). For instance, when the driver looks at the left external mirror, the interaction context could be set to either implicitly select this mirror as interaction object. At least the disambiguation (left / right / internal mirror) can be skipped in this case if the driver only says “mirror” as a command. This way, the user behavior (in this case: the user’s gaze) can implicitly be used to support the interaction (Schmidt 2000).

For the current prototype, we focused on objects that are mostly visible in the driver’s environment. Thus, it is easy to remember the items of the interaction space and their names, which helps to support the visibility principle. Using single words as starting point can also help to increase the users' willingness to explore. With this approach a large amount of items and functions can be addressed without an increased memory load on the users' side. In order to provide the most convenient interface to the user, for the selection process it is necessary to allow the use of a variety of synonyms for the different objects and functions.

Manipulation

Once the interaction object(s) and function have been selected, the driver can perform a touch gesture on the steering wheel to complete the intended action. Using the surface of the steering wheel as space for touch input has the advantage that for most interactions one or even both hands can reside on the steering wheel. Touch gestures as a form of interaction, e.g., moving a finger across a touch-sensitive surface (touchpad / touch screen), allow for a fine-grained manipulation by moving the finger for a certain distance. For instance, if the gesture is a simple directional gesture (finger movement on the touch surface in a certain direction), the length of the gesture defines the amplitude of the manipulation. As the action/manipulation of the selected object is executed at the same time, immediate feedback is by the corresponding change of the selected objects (e.g., the mirror changes its orientation as the user moves the finger over the touchpad). It also provides simple means for undo of an action by performing the inverse movement. For example, if the mirror has been rotated too far to the right by a right-facing directional gesture, the adjustment can be inverted by perfoming the inverse gesture, i.e., a left-facing directional gesture.

Benefit of the Interaction Style

Overall, speech allows selecting functions and objects by just naming them (including a range of synonyms) without a need for deep hierarchical structures or explicit menu-based navigation. Touch gestures support fine-grained control of functions and easy undo/redo means. In the automotive context, previous research has shown that gestures are powerful as they require minimal attention and can be performed without taking the eyes off the road (Döring et al. 2011), whereas interaction with (graphical) menus and lists is visually much more demanding and results in a higher distraction. Finding intuitive gesture commands to manipulate functions can be difficult and hence particular care has been taken to find appropriate gestures. Our developed multimodal interaction style adheres to all goals stated above. By separating selection of object or function from the manipulation of the function, the same touch gesture can be reused for several actions that are distinguishable by their speech invocation (1:n mapping from gestures to functions) and hence gestures remain simple and easy to remember.

We expect that the presented interaction style will reduce the visual demand during interaction. Furthermore, such an approach could potentially be applicable beyond the car for all settings where the functions and objects to control are visible (e.g., smart environments) and where fine-grained control and undo/redo are important.

5.3 Formative Study

To explore the combined use of speech and touch gestures in the specific context of the car, we conducted a formative study to investigate user-defined voice commands and gestures. In this study, we wanted to address two research questions: (1) How do users name or address the objects and functions they need to control without prior training? (2) Which touch gestures do users perform in order to control a function on a selected object? We developed this experiment by following the methods proposed by Wobbrock, Morris, and Wilson (2009) who investigated user-defined touch gesture sets for tabletop interaction. This allowed us to extract and redact speech commands for the selection of objects and user-defined gestures for the manipulation. The output of this experiments, i.e., the identified speech commands and touch gestures, serves as input for a prototypical implementation and evaluation of the proposed interaction style.

5.3.1 Study Design and Setup

For the user study, we chose a scenario of controlling 26 secondary and tertiary functions in a car (i.e., safety and comfort functions). All selected functions are elementary one-step functions where a simple manipulation of the selected interaction object takes place. The selection of tasks also concentrated around well-know functions that should be commonly known to the average driver as well as they should somehow be visible to the driver. To gather the set of functions, we consulted the manuals of several car models (including Mercedes-Benz E and CLS class and BMW 5 series) in order to take into account the most common features. Additionally, we especially considered functions where the operation with physical controls today requires the driver's (visual) attention. Also, we mainly focused on functions that we do not expect to disappear during the next years, e.g., due to the introduction of new sensors.

Figure 5.2: Study setup of the formative study. The scenarios were presented on a display that was mounted to the steering wheel. This speech-enabled multi-touch steering wheel allowed to record speech commands and touch gestures. For a more realistic environment, the experiment was conducted in a simple driving simulation.

We performed a within-subject experiment where each participant proposed commands and gestures for every of the 26 functions. For each function, the driver was first presented one or two images to identify the object and function to interact with and was asked to produce a voice command for this object. Next, a pre-recorded instruction asked the participant to perform a gesture on the steering wheel in order to perform the according manipulation of the object shown before.

The study took place in a lab environment as shown in Figure 5.2. Our setup included a speech-enabled multitouch steering wheel. Besides the necessary images to identify the objects and functions for the investigation of the speech commands, no additional visual or auditory feedback was given as a response to voice commands or gestures. We integrated an Android-based tablet (Motorola Xoom) into a wooden steering wheel that was mounted on the base of a Logitech G27 steering wheel to enable multitouch input. A voice and gesture recording app was installed to present the different scenarios on the tablet and record the speech commands and touch gestures. When the app was waiting for gesture input, only a white background was shown without displaying any gesture trace. Since the Android tablet allows multitouch input, also gestures that involved multiple fingers could be recorded. The Logitech G27 steering wheel base also served as input for a PC-based driving simulation (CARS simulator, see Kern and Schneegass 2009) that we presented on a 24 ” screen to provide the illusion of a driving scenario.

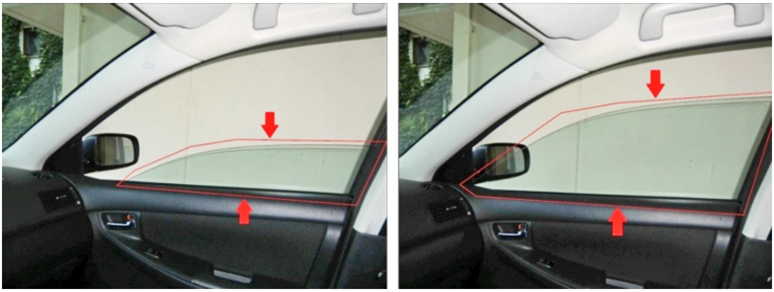


Figure 5.3: Exemplary instruction image for one of the selected task. In this case, the participant should find a speech command and a touch gesture to close the passenger window by one third. First, the driver had to identify and name the object (and function) that has been modified. Next, a touch gesture should be performed that the participant would use to achieve the behavior that is shown in the images.

5.3.2 Participants and Procedure

We recruited study participants through institution mailing lists and personal communication. They were required to have a driver's license and received a compensation of 5 € for their participation. The experiment lasted 35 minutes on average. In total, 12 people took part (2 female) aged between 20 and 39 years ($M = 28.2$ years, $SD = 6.58$ years). The participants had an average driving experience of 10.6 years ($SD = 7.3$ years) and car usage ranged from twice a month (2 participants) over regularly (6 participants) to every day (4 participants). Five participants owned a car and ten of the participants were right-handed. Four of the participants already had experiences with speech interaction. Nine of them already had used a touch-enabled device (mainly phones/tablets) before.

We started the experiment with a short introduction to the research context, explained the interaction style and the procedure. Next, the participants had to sign a consent form and filled out a demographic questionnaire. After that, the participants were seated in front of the simulation environment. We chose to use a simulator in order to make the participants aware of the driving situation which might influence the way how gestures are performed. The driver had to drive along a 2-lane infinite highway where blocking obstacle indicated necessary lane changes. A fixed speed was pre-programmed and the drivers were instructed to keep at least one hand on the steering wheel. They should only avoid obstacles while performing a gesture. Further, they were told to use either one or multiple fingers to do a gesture.

The main part of the experiment consisted of 26 tasks (see Table 5.1), which were presented to each participant in a permuted order to avoid learning effects. Each task consisted of three parts.

1. The participants were presented one or two augmented photographs on the steering wheel screen showing the initial state and the final state of an object in the car. An example of this is illustrated in Figure 5.3. We asked the participants to verbally address the object/function and spontaneously provide a unique name. Furthermore, we stressed that the wording should be unique since objects might occur multiple times in the car. The use of "before-and-after" images should help the participants to not only understand which object is shown but to also understand the desired function and manipulation. In order to not prime the use of a certain wording we gave no textual or verbal instructions. If the participant did not present a name precisely enough to specify the object or function, the experimenter asked to refine the command (e.g., user: "seat"; experimenter: "which seat?").

2. Once the participant addressed object and function, the app on the tablet asked to suggest a touch gesture (s)he would use to specify the parameters (e.g., moving the driver's window half way down). This request was presented as a voice instruction by the app. No auditive or visual feedback was given for both voice commands and touch gestures. If desired, the participant was allowed to repeat or overwrite the gesture of the current task.

3. The participants were asked to rate the difficulty of producing the speech command and touch gesture for each task.

The three steps were repeated for each of the tasks. They were monitored by the experimenter in order to prevent advancing before a suitable speech command or touch gesture was presented. There was no time limit given for any of the tasks and the participants should use any time to look at the images, to identify objects and functions, and to produce a touch gesture. At the very beginning, one additional task was presented to explain the procedure. During all steps, the participants were asked to think aloud in order to be able to recognize their mental processes afterwards.

At the end of the study, users filled out a final questionnaire. We asked them to rate the acceptance of the proposed interaction style as well as details about the performed touch gestures. Next they should rate the usefulness of the interaction style for each category of tasks (adjust wipers, longitudinal seat position, headrest height, backrest inclination, open/close windows, seat height, head-up display, cruise control, vent intensity, seat heating, external mirrors) that they experienced during the study. Finally, the participants were encouraged to discuss advantages and disadvantages of the presented approach and to suggest additional use cases.

5.3.3 Results

Collected Speech Commands

In 305 of the 312 tasks (i.e., 97.8 %), the participants were able to find appropriate terms/speech commands for the objects and/or their functions that were presented during the first part of each task. The head-up display was the only object where seven participants did not succeed in finding an appropriate term. In general, the participants had the most difficulties to name head-up display and cruise control.

As the images already suggested the intended action by showing the situation before and after executing the task, the participants could have chosen to directly name the function of the object (e.g., “move the driver’s seat"). Nevertheless, only a minority chose this option (16.1 %). Most users only named the objects themselves (e.g., “driver’s seat", 82.1 %) but no function. The evaluation of the voice command showed further that the participants used a variety of terms for the same object (e.g., right mirror, right exterior mirror, mirror on the passenger side, exterior mirror on the passenger side, adjust exterior mirror right . . .). A similar variation of commands was noted throughout all tasks. Even though this variation occurred, the object (and partially its function) could be identified accordingly. As a conclusion, we believe that the denotations of visible objects have potential for intuitive speech commands.

Touch Gestures

When analyzing the recorded touch gestures, the study reveals a high agreement on touch gestures among participants. Overall, the participants did not have problems to invent touch gestures and chose very similar and simple gestures to control most of the functions. For 309 of the 312 tasks, the participants were able to produce a meaningful touch gesture. For 78.1 % of these 309 gestures the participant used only one finger, 12.9 % resp. 6.8 % of gestures were done with two or three fingers. In 1.6 % of the cases, 4 fingers were used. Five fingers were

Table 5.1: List of the different tasks of the formative study. The last five columns show the frequency of the touch gestures performed for each task. Arrows symbolize a simple directional gesture in the corresponding direction. If gestures other than directional ones where performed, these are summarized in the last column.

Object	**Task**	**Function**	**Touch Gestures**				
			↑	↓	←	→	other
Driver seat	1	move forward	8	-	4	-	-
	2	move back	-	7	-	5	-
	3	move up	12	-	-	-	-
	4	move down	-	11	-	-	1
	5	headrest up	11	-	-	-	1
	6	headrest down	-	12	-	-	-
	7	backrest forward	8	-	4	-	-
	8	backrest back	-	8	-	4	-
	9	increase heating	12	-	-	-	-
	10	decrease heating	-	12	-	-	-
Right exterior mirror	11	move left	-	-	12	-	-
	12	move up	11	1	-	-	-
Front wiper	13	off	-	4	4	1	3
	14	permanent	2	-	-	4	6
	15	interval	1	-	1	4	5
Rear wiper	16	clean+wipe	1	-	-	2	7
Passenger window	17	open partially	-	8		-	4
	18	close partially	8	-	-	-	4
Backseat window (l)	19	auto open	-	11	-	-	1
	20	auto close	12	-	-	-	-
Cruise control	21	accelerate	-	11	-	-	1
	22	decelerate	11	-	-	-	1
Left air vent	23	more air	11	-	-	1	-
	24	less air	-	11	1	-	-
Head-up display	25	increase brightness	10	-	-	1	1
	26	decrease brightness	-	11	-	-	1

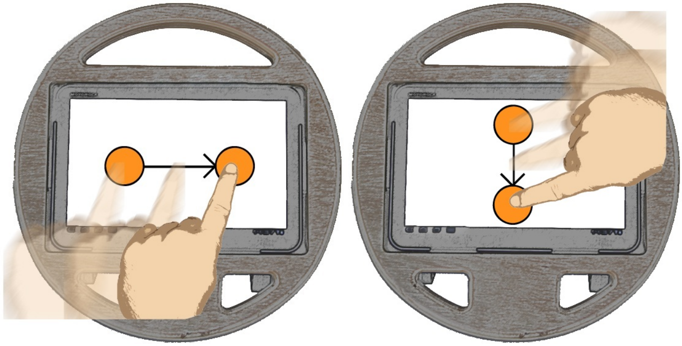


Figure 5.4: Examples of directional gestures as they were performed by participants during the formative study.

used only once. One third of the gestures was performed using the left hand, both hands were involved only twice.

If we consider the type of the 309 recorded meaningful gestures, 86.7 % of them were simple directional touch gestures where the finger was moved to a certain direction on the touch screen. As shown in Figure 5.4 and Table 5.1, the main direction of such a gesture was either up/down (37.9 % resp. 34.3 %) or left/right (8.4 % resp. 6.1 %). These gestures were conducted with one or multiple fingers and the participants drew their gestures either as a straight or slightly curved line. For a real-world implementation, these directional gestures also allow an easy undo feature: To undo an action, just the direction of the drawing gestures has to be inverted. Moving the finger(s) to more than one direction (e.g., “zoom gestures”, moving left and right as one gesture) occurred for 7.8 % of the performed gestures. Another 5.5 % of the gestures were conducted without a certain direction (e.g., circular gesture, single tap).

As shown in Table 5.1, for six of the presented tasks (move driver seat upwards, move headrest down, move right exterior mirror to the left, increase intensity of seat heating, decrease intensity of seat heating, auto-close backseat window) all 12 participants decided to produce the same gestures for the specific task. Similarly, for 8 tasks all but one participant made the same gesture as did 10 of them for two other tasks. The performed gestures were either drawing one or multiple fingers up or down. These gestures were used to move an item upwards, increase a value, or do the opposite action. Instead, for task #11 a directional gesture to the left was recorded to move the exterior mirror to the left. For the task of moving the seat (#1, # 2) or backrest (#7, #8) to the front or back, still 8 respectively

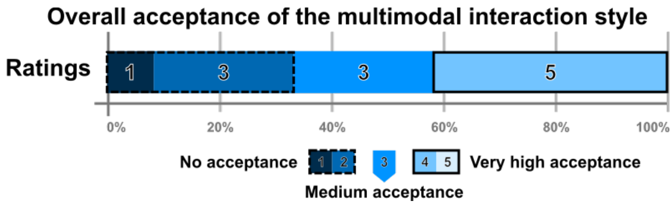


Figure 5.5: Overall acceptance of the multimodal interaction style. Figure generated using http://likertplot.com (Maurer 2013).

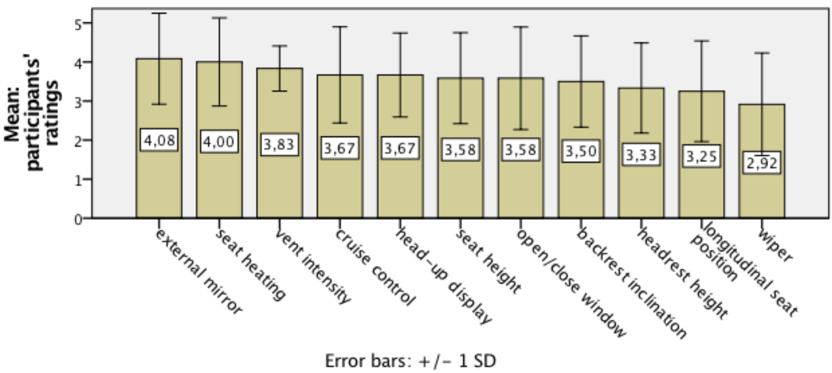


Figure 5.6: Participants' mean ratings of how suitable the interaction style is for the different tasks performed in this experiment on a Likert scale from 1 ("I do not agree at all") to 5 ("I fully agree").

7 participants performed the same up-/down-pointing gestures. The rest of the participants used drawing gestures pointing to the left or to the right. This might have been caused by the shown picture of the seat where the front of the seat was on the left side. Additionally, almost all participants stated that they tried to create gestures consistently.

Users' Evaluation of the Interaction Style

We asked the participants to rate the overall acceptance of a system that uses the presented multimodal interaction style on a 5-point Likert scale ranging from 1 (no acceptance) to 5 (high acceptance). The results show a medium acceptance ($M = 3.0$, $Mdn = 3$) as also shown in Figure 5.5. For each of the involved task categories, we also asked the participants to rate on a 5-point Likert scale from

1 (“I do not agree at all”) to 5 (“I fully agree”) whether they assume that the proposed interaction style is suitable for this task category. Figure 5.6 shows that the participants rated the external mirrors ($M = 4.08$, $SD = 1.11$) and the seat heating ($M = 4.00$, $SD = 1.08$) highest and the wiper control lowest (slightly below undecided, $M = 2.92$, $SD = 1.26$).

Difficulty of Speech Commands & Touch Gestures

Of all tasks executed, 30.1 % of the given commands and gestures were rated “very easy”, 46.5 % were graded “easy” and 15.7 % “medium”. In 6.1 % of the presented cases, users rated gestures as “difficult”, leaving 1.3 % of commands and gestures that were “very difficult” (one task was not rated, 0,3%).

Individual Feedback

The participants also had the chance to provide additional feedback about the proposed interaction style. This was especially related to additional use cases where they would like to use this interaction style. Five of the participants stated that they would also like to operate the radio / entertainment system using speech and gestures. Similarly, 4 participants would use it for navigation purposes and 2 participants would operate the hands-free phone. Other proposed use cases were MP3 player, trip computer, sunroof, driving mode (sport, eco), headlights, and child safety lock (all mentioned once).

When asked about benefits of the approach, the participants stated that they would expect the system to have a lower distraction (3x), to support the clarity of the cockpit, and to spare the search for certain controls. Also, one participant liked that the touch gestures facilitate certain fin-grained adjustments that would be difficult to perform by using speech only. Similarly, another participant stated that touch gestures facilitate the adjustment of continuous values. One participant liked that (s)he does not have to (visually) focus on the object to interact with. Another participant assumed that touch gestures speed up adjustments. Also, it was stated that it is beneficial that no menu navigation is required and that everything can be operated from a single place, i.e., the steering wheel. Finally, one participant found the approach to be very comfortable.

The disadvantages of the approach as seen by the participants especially related to potential recognition errors of speech commands and touch gestures. The participants mentioned that an imprecise or erroneous recognition could be a disadvantage or that recognition errors could distract and thus endanger the driver. It was also mentioned that the disambiguation might be tricky, or that sometimes a gesture would be redundant if the activity can also be fully explained using speech.

Furthermore, it was mentioned that the interaction might cause an increased cognitive load or that some tasks might be less suited for this interaction style. As a conclusion, it was stated that a system needs to provide well-designed methods for error handling of speech recognition. Also, certain situations such as listening to loud music or driving in the morning ("when I do not want to talk") or when driving with passengers were expected to be less beneficial for this approach. One participant stated that it was a strange feeling to talk to a computer and another participant was worried about the additional price for buying and maintaining such technology.

5.3.4 Discussion

The formative study reveals several interesting insights regarding the proposed multimodal interaction style. Across all participants the users' impression about the suitability of this approach for different task varies. Especially for adjustment tasks such as adjusting the mirrors and seats, modifying ventilation or heating, and setting the cruising speed the participants agreed that the approach is useful. Also, for more than 90 % of the tasks the perceived difficulty was between very easy and medium. These findings encourage to continue an investigation the concept.

For the speech commands we observed that the participants mostly did not have any difficulties to produce appropriate commands. Since there was no training on the environment or interface involved, this fact shows that the use of such a speech-enabled system would only require little or no learning, which is one of our pursued goals. Also, due to the selection of functions and objects, we support the design goal to maximize visibility of command options. Since the participants used a variety of speech command to address objects and functions, it is important that a future system provides the flexibility to use any of the imaginable synonyms to address an object or function. Thus, during the development of such a speech-enabled system it is recommended to perform a large-scale experiment in order to collect an extensive set of words and synonyms beyond those that can be found in dictionaries and thesauri. As also stated in the subjective part of the final questionnaire, the quality of speech recognition is one of the key aspects. This relates both to the variety of the accepted commands as well as to the technical quality of the recognizing system.

Similar to the speech commands, the participants also proposed touch gestures for almost all tasks. While clearly related to the context of the specific task, it is interesting to see that for almost 90 % of the interactions, simple directional touch gestures were used to operate the system. The direction of the movement either related to the actual movement of the object (i.e., a natural mapping between gesture and intended movement) or to common (cultural) conventions such as moving a control upwards to increase a value and vice versa. The simple properties of these directional gestures facilitate performing and remembering each gesture as well as the implementation of a gesture recognizer is rather simple. Additionally, manipulations are fine-grained (design goal 3) and can easily be reversed by stopping the finger movement and resuming the opposite gesture. Thus, the interaction style also supports design goal 4 to support simple undo of actions. As the directional gestures can be used across different situations, it should also be possible to create consistent user interfaces (design goal 5). Overall, the drawing gestures are based on embodied conceptual metaphors and seem well-suited to control the parameters of most objects' functions.

As a summary we see that the multimodal approach has the potential as an alternative input method in the car. To implement the interaction style for most of the activities used in our study, it is sufficient to collect a set with different words that can be used to address object and/or function. For the recognition of touch gestures, the recognition of simple directional gestures covers most of the use cases. The most simplistic recognition processes the horizontal or vertical movement of a finger on the touch surfaces and maps these changes to the adjustment of the selected object. With this regard, it is recommended to implement a mapping that is easy to understand. From our experiment, we recommend to map movement to the left or to the bottom to a decreasing function and vice versa. For objects with real movements, a natural mapping is recommended.

To continue the evaluation of the interaction style, we therefore built a prototype that draws from the findings of this formative study. For this prototype, we still focus on controlling those objects and functions that were also subject of the formative study. However, as stated by the participants, it may be worth to consider the IVIS as an additional application domain for this multimodal interaction style. The implemented prototype and the study that evaluates this prototype will be presented in the subsequent sections.

5.4 Prototype

We designed and implemented a prototype that allows us to evaluate the proposed multimodal interaction approach. The prototypical environment is set up in our lab and comprises several components, including a driving simulator, additional

Figure 5.7: Setup of the prototype to evaluate the multimodal interaction style in a driving simulation: The participants use a customized steering wheel and pedals to drive in a driving simulator such as the LCT environment shown in this example. Additional screens around the driver simulate windows and external mirrors on the left/right side of the vehicle as well as the rear window and wiper (not shown here). The multitouch-enabled steering wheel allows for touch gesture input, and a microphone enables the use of speech commands.

screens to simulate certain functions and objects in the car, the touch-enabled steering wheel, and a speech recognition component.

Since we did not have access to a fully equipped vehicle or simulation environment, we limited the set of available functions to those features that we are able to easily simulate in our prototypical environment. These comprise: (a) the adjustment of the ventilation intensity (left/right), (b) the cruising speed for cruise control, (c) the intensity of the seat heating, (d) the brightness of the head-up display, (e) operation of driver and passenger windows, (f) adjustment of the external mirror positions (left mirror: up/down, right mirror: left/right, due to technical video limitations), (g) virtual adjustment of the driver seat position, and (h) state of the rear windshield wiper.

The driving simulation environment consist of different components that simulate the driving scene and certain components of the car interior as shown in Figure 5.7. This simulator itself consists of four to five displays, one for the driving scene and three to four to simulate the surrounding of the cockpit. They are arranged around the driver's seat to simulate the driver's workplace: A 55 " LCD TV[3] in front of the driver shows the normal output of a driving simulation. Here, various simulation programs may be used such as CARS (Kern and Schneegass 2009), OpenDS[4], or the specific LCT software (Mattes 2003). In order to allow driving the simulated car, we mounted our customized, wooden steering wheel to the base of a Logitech G27 gaming steering wheel. Also, the pedals of this gaming package are connected to the computer in order to accelerate and slow down the car. Two 24 " screens are arranged on the left and right side of the driver showing a pre-recorded static view of a real driver and passenger window. These screens are used to visualize the movement and behavior of the external mirrors and the windows when interacting with them. To visualize the behavior, videos were taken where the windows or mirror position changed. If the driver interacts with one of these objects, the video is played back accordingly. Once the interaction stops, the video is paused to show the still image of the current position of the windows and mirrors. Another 24 " screen visualizes the rear window showing an interactive wiper that the driver can interact with. Again, this view has been pre-recorded and is adjusted according to the driver's interaction. At last, an optional netbook screen provides an instrument-cluster-like output space behind the steering wheel. On this screen, the driver can see a speedometer, and a multifunctional space for visual output as it is used in many instrument clusters. As the setup does not comprise a physical center stack, also the status of the seat heating is visualized here. The netbook screen is mainly used in case the driving simulation itself can only be run in full-screen mode. Otherwise, the lower part of the TV screen is used to display this information as shown in Figure 5.8. If the latter is used, an extended dashboard view also shows an imitation of the air vents and a visualization that provides feedback about the vent intensity.

Two desktop computers (Windows 7) run the driving, window, and mirror simulations and feed the corresponding screens. The netbook additionally provides the dashboard output on the fifth (netbook) screen. The software architecture is built to allow addressing further input modalities such as gaze or posture input. Different functionalities such as recognizing touch or speech input are realized in separated components. The communication between these components is based on the EIToolkit developed by Holleis and Schmidt (2008). This toolkit allows a loosely coupled architecture as shown in Figure 5.10 by utilizing UDP broadcast messages. A conceptual overview of the involved components and their connections is shown in Figure 5.9.

---

[3] Philips 55PFL7606K/02

[4] http://www.opends.de, last access: 2015-10-20

Figure 5.8: Screenshot of the driver's view: Most part of the front TV screen is used to display the driving scene that is augmented with a rudimentary head-up display. The lower part shows the vehicle dashboard including visual representations of air vents, speedometer as well as an output space for additional visual feedback.

In order to allow touch input on the steering wheel, we use the multitouch-capable Motorola Xoom tablet that we integrated into the steering wheel as touch input source. On this tablet, an Android application[5] allows the user to enter multi-touch gestures on its entire interactive surface. In contrast to the other components, here we use the TUIO protocol[6] to send the touch input to the gesture recognizer that is then connected to the main interaction framework through the EIToolkit. The gesture recognizer mainly looks for horizontal and vertical changes of a finger that touches the surface and maps this to the modification of the selected object. If the steering wheel is rotated, this rotation is already removed by the app that runs on the tablet. The steering wheel pedals are also used as triggering elements to start speech interaction.

We implement the voice recognition component by exploiting the Microsoft Speech SDK on one of the desktop computers. It uses a simple grammar to understand users' speech commands and implements the *disambiguation cycle* (see Figure 5.1). A consumer microphone is connected to the computer in order to grab the spoken input. In order to extend the robustness and usability of the

[5] Google Code: TUIOdroid - http://code.google.com/p/tuiodroid, last access 2015-04-20

[6] http://www.tuio.org/, last access: 2015-10-20

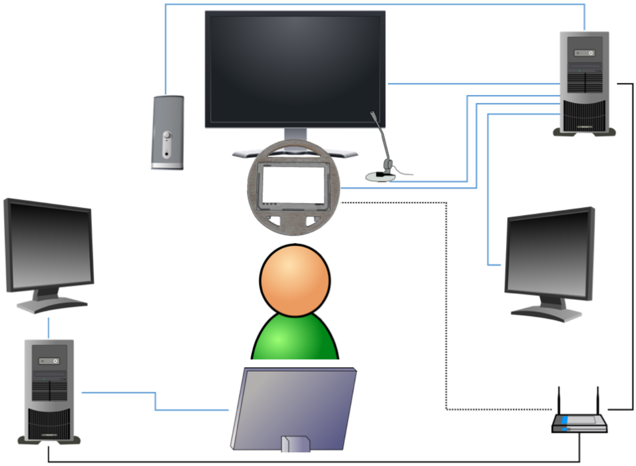


Figure 5.9: Conceptual overview of the implemented multimodal prototype. Two desktop computers feed the screens that show the simulation of the driving scene and the windows and external mirrors. The multitouch-enabled steering wheel with its pedals is used to drive the simulated vehicle. Using a WiFi connection, touch input from the steering wheel (i.e., from the integrated Android tablet) is broadcasted to the gesture recognizer that is running on one of the desktop computers. A speech recognizer uses the microphone to detect speech commands. Similar, different controller stubs are in charge of providing visual output to the screens or auditive feedback. A central component merges all input data and generates appropriate output for the output stubs. The different components communicate using the EIToolkit (Holleis and Schmidt 2008).

speech input, the system provides additional visual output on the dashboard. For instance, if the uttered speech command is ambiguous, the available alternatives are presented on the dashboard screen. This may also help to recover from erroneous inputs. The speech recognition can be started by pulling one of the pedals from behind the steering wheel (usually used for gear shifts) as a "pull-to-talk" control. Since the system is permanently listening for input, the driver can also use the word "command" (or its German translation) to activate speech recognition. A typical interaction sequence using the implemented interaction style is as follows:

1. The driver activates the speech recognition by pulling one of the steering wheel pedals (“pull-to-talk”) or says “command” as a triggering keyword. This action is confirmed through an acoustic signal.

2. For the next seconds the system waits for speech input. If input is detected, the disambiguation process is followed:

   (a) If the selection is unambiguous, this is immediately confirmed by a positive beep sound along with an auditive repetition of the command using text-to-speech synthesis.

   (b) If the selection is not complete, an informative beep is provided along with a spoken instruction (synthesized voice) to fully specify the object and function of interest. A short list with available functions and commands is provided as additional help on the dashboard screen. This step is repeated until the selection is unambiguous.

3. Once object and function have been selected, the modality switch takes place. Now the driver can use touch gestures on the steering wheel to perform the intended manipulation. Undo is possible by performing the opposite gestures.

4. If the system does not recognize speech or touch input during a short time frame, the interaction sequence is terminated and the driver can start from the beginning. The same happens if no further input is detected at the end of an interaction sequence.

The formative study provided the basis command sets for the speech commands and gestures used in this prototypical implementation. For speech commands, we included variations for each object and function. The input data is processed in the interaction framework. The generated output includes the information about the manipulated object and the action that takes place. This output (e.g. a moving mirror or opening window) can be processed in the car or be interpreted and visualized by the car environment simulator.

5.5 Evaluation

In a second study we investigated the influence of the proposed interaction style on driving, user experience, and usability. We compared the proposed system to a traditional interface as it is known from current cars. Again, we focus on primitive,

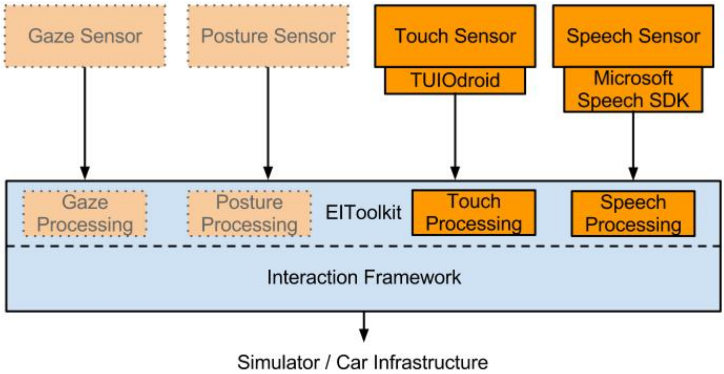


Figure 5.10: Input architecture of the prototype that implements the proposed multimodal automotive interaction interaction style. Each component that receives input data processes this information and distributes it to the interaction framework by means of the EIToolkit. A central component of the interaction framework processes all input data and controls the output to the different screens and auditive feedback.

one-action tasks that neither require a long interaction time nor the use of more than a single input element in the traditional setting (e.g., opening the window). Basically, this interaction does not need long practicing from participants and is easy to understand.

Another reason for choosing these simple actions is that it seems obvious that functions hidden somewhere in the menu need more time to execute and result in a long interaction time leading to high visual distraction due to the attention shift as described by Schneegass, Pfleging, Kern, et al. (2011). During the study, participants only have a short period of time for practicing each interaction technique. Confronting them with an actual in-car menu would take significantly more time to master it and some function would maybe not be found at all.

5.5.1 Method

Design

In this study, we used a within-subjects design. There was one independent variable, namely the interaction style, with four different levels: no interaction (baseline 1), traditional interaction, multimodal interaction style, and no inter-

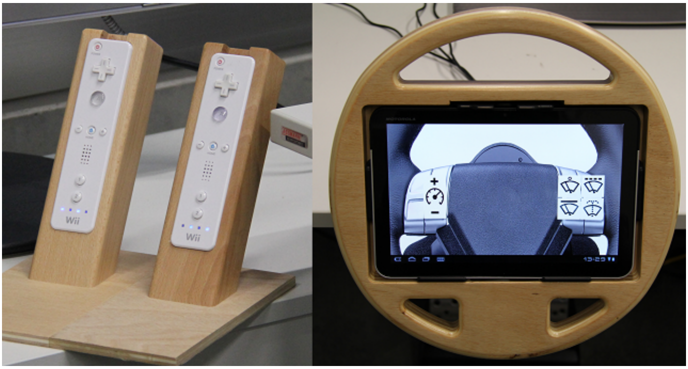


Figure 5.11: We used two WiiMote controllers and touch buttons on the steering wheel to replicate a traditional automotive interface for the traditional interaction condition.

action (baseline 2). As dependent variables, we measured the mental workload using the Driver Activity Load Index (DALI) (Pauzié 2008, see also Section 2.6.1) and the usability by employing the System Usability Scale (SUS) (Brooke 1996, see also Section 2.6.1). Additionally, driving performance was measured using the Lane Change Test (LCT) software as a driving simulation and to analyze the driving performance. Thus, we also measured the mean deviation between path trajectory and actual driven path (*mdev*) (see Section 2.6.3 for a detailed explanation).

Since we used a within-subject design, all participants drove four laps, namely: a first baseline drive without NDRA, one lap where the multimodal interaction approach was tested, anther lap where the traditional interface was tested, and a concluding baseline ride. We used one baseline ride at the beginning of the experiment and one at end of the experiment in order to observe whether the driver performance changes during the experiment. The two interaction conditions were alternately changed (randomized over the participants).

Apparatus

Besides the baseline conditions where no additional task should be performed while driving, we used two different conditions during the user study: in the traditional condition a conventional interface was used as explained in the next paragraph while the multimodal style was used in the multimodal condition. Both

Table 5.2: Overview of the objects and functions to interact with during the evaluation of the multimodal interaction style.

Object	Function	Initial state
Left external mirror	move up completely	center position
Left external mirror	move down completely	center position
Right external mirror	move completely to the left	center position
Right external mirror	move completely to the right	center position
Rear wiper	permanent wiping	off
Rear wiper	interval wiping	off
Rear wiper	spray	off
Rear wiper	turn off	wiping
Driver window	close window to one half	fully open
Passenger window	open window to one half	fully closed
Set cruising speed	increase speed by at least 15 km/h	30 km/h
Set cruising speed	decrease speed by at least 15 km/h	30 km/h

were tested in our driving simulator environment. As driving simulation, we used the LCT software.

The traditional condition used a setup where digital and tangible input elements (see Figure 5.11) were arranged in the way as they can be found in current cars. We used two WiiMote controllers to reproduce typical controls to operate windows and external mirrors as we find them today typically as part of the driver's outer armrest. A Bluetooth dongle was connected to one of the computers in order to receive and process the input to these WiiMote controllers. This was done as a WiiMote stub that provided this information to the other system components using EIToolkit. The speed limiter/cruise control and wiper controls were realized as soft (touch) buttons of an Android app that ran on the touch-enabled steering wheel. Similar buttons can be found on current steering wheels. The idea of the overall setup was to mimic a current car environment that should be operated while driving.

In the multimodal condition, the previously described multimodal prototype was used. Since the driving simulation had to be run in full screen mode, we used the setup with the additional netbook screen to visualize parts of the dashboard and instrument cluster.

For the study itself, we reduced the number of objects and functions to interact with to the set shown in Table 5.2

Participants

In total, 16 participants took part in the user study (all male). Again, we recruited them through advertisements on our mailing lists and personal invitations. Therefore, different participants took part in comparison to the formative study. The participants were between 21 and 29 years old ($M = 23.8$ years; $SD = 2.35$ years) and all of them possessed a valid driver's license. Each participant was an experienced driver with a driving experience ranging from 3 to 10 years (7 years on average).

Procedure

At the beginning of the experiment, we asked each participant to set up the driver seat so that (s)he can reach all controls as good as possible. Afterwards, we introduced the study purpose to them. The first lap was a baseline lap where each participant drove along the track without any secondary task. On the second and third lap, each participant performed as many tasks as possible while driving along the LCT track (3 minutes) either with the multimodal or the traditional interaction approach. Before each participant performed the actual lap using one of the approaches, we introduced them to the corresponding interaction concept and encouraged them to practice the different tasks until they felt comfortable. At the end of each condition the participants filled in a SUS and DALI questionnaire. As a fourth and final lap, each participant performed another baseline lap. We used a final questionnaire to ask for additional subjective feedback about the proposed interaction style.

5.5.2 Results

Figure 5.12 shows the mean mdev measurements for each condition. Mauchly's test failed to detect a violation of the sphericity assumption in our mdev data, $\chi^2(5) = 6.40,\ p > .05$, therefore no corrections to degrees of freedom are needed. The results show that the mean deviation from the reference path was significantly affected by the driving condition, $F(3,45) = 21.77,\ p < .01,\ \eta^2 = .592$. Bonferroni post hoc tests revealed a significant different in the mdev measurements only between baseline 1 and traditional interface, baseline 2 and traditional interface, baseline 1 and multimodal interface, and baseline 2 and multimodal interface, $p < .05$. No other comparisons were significant (all $ps > .05$). Thus, we see a significant difference of the mdev value between the base line drives and the interaction conditions, but cannot reason a significant difference between the traditional and the multimodal approach.

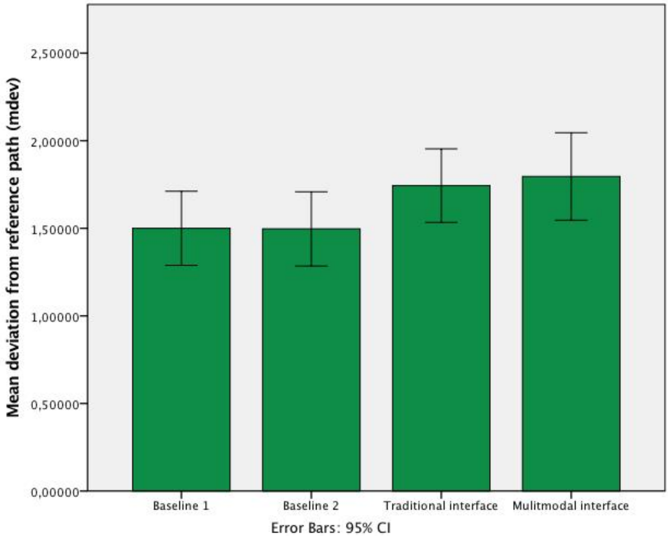


Figure 5.12: Means and standard errors as error bars for mdev measurement as an indicator for driving performance in each condition.

In addition to the quantitative data measured, we asked the participants to provide feedback after using an interaction technique. We measured the feedback with SUS and DALI questionnaires to extract perceived usability and perceived task load. On average, the reported SUS results using the traditional interface ($M = 79.38$, $SE = 3.50$) was significantly higher than using the multimodal interface ($M = 69.06$, $SE = 2.728$), $t(15) = 2.5$, $p < .05, r = .22$.

Analyzing the results of the DALI questionnaire, the reported *unweighted DALI score* using the traditional interface ($M = 2.30$, $SE = 0.22$) was slightly lower than using the multimodal interface ($M = 2.52$, $SE = 0.16$). However, significance cannot be reasoned ($t(15) = -.99$, $p = .33$, $r = .06$). Comparing the single dimensions used for the DALI questionnaire (see Figure 5.13), one can observe several significant differences. On average, the reported *visual demand* using the multimodal interface ($M = 2.31$, $SE = 0.299$) is significantly lower than using the traditional interface ($M = 3.19$, $SE = 0.245$), ($t(15) = 2.333$, $p < .05$, $r = .27$). In contrast, the reported *auditory demand* using the multimodal interface ($M = 2.55$, $SE = 0.302$) is significantly higher than using the traditional interface ($M = 0,5$, $SE = 0.129$), ($t(15) = -7.766$, $p < .001$, $r = .8$). The third dimension with significant differences is the manual demand. The reported *manual demand* using

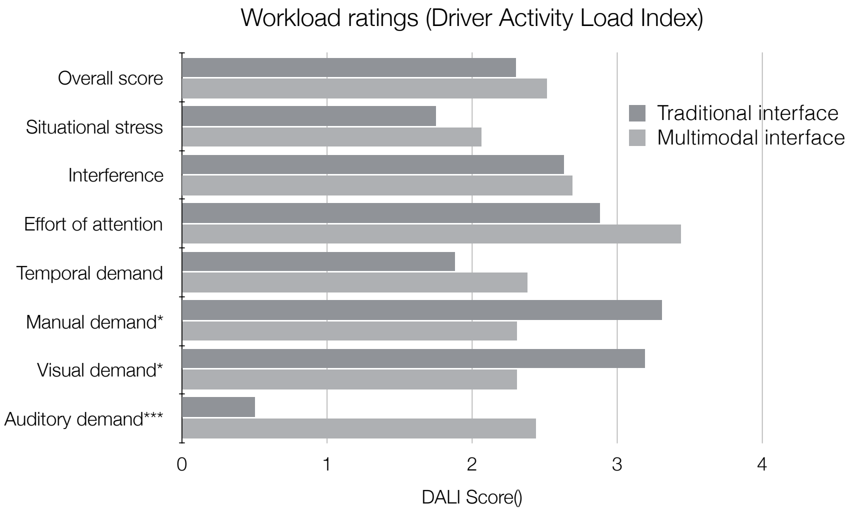


Figure 5.13: Means of the different DALI dimensions as indicators of subjective workload for the two interaction conditions.

the multimodal interface ($M = 2.31,\ SE = 0.285$) is significantly lower than using the traditional interface ($M = 3.31,\ SE = 0.326$), ($t(15) = 2,449,\ p < .05,\ r = .05$). For the remaining DALI dimensions, no significance can be reasoned.

5.5.3 Subjective Feedback

In the final questionnaire, we wanted to receive additional feedback about the proposed interaction style and prototype. 11 of the 16 participants imagined that they would use the multimodal interaction style as a preferred technology. Similar to the formative study, participants stated that they would like to use the approach also to operate radio, music, and other multimedia functions. Also, the navigation system and air conditioning features were mentioned as application domains.

When asked about advantages of the multimodal approach, the participants stated that they expect this interaction style to be less distracting since the selection of controls requires less attention as well no control needs to be focused visually. The participants also liked the central location of the interaction space and that the interaction style enables a clean cockpit with less buttons.

The most frequently mentioned drawbacks of the multimodal approach are related to the error detection for speech commands and a misclassification of gestures. Also, it was mentioned that the interaction duration might increase due to the use of speech interaction.

5.5.4 Discussion

The analysis of the results shows that multimodal interaction style performs similar to the traditional approach of using physical controls one-action interaction. Interacting with the multimodal prototype did not yield a significant difference with regard driving performance in comparison to the use of traditional controls.

The subjective rating that we collected using the SUS showed that the traditional interface outperformed the multimodal interaction style. During the experiment, we observed certain situations where the speech recognition failed. We expect this to be one reason why the usability of the multimodal approach has been rated lower than the use of traditional controls. However, according to Bangor, Kortum, and Miller (2008) the achieved score is still within acceptable range. For a future experiment, we would perform the speech recognition part as a wizard-of-oz experiment in order to eliminate the issue of recognition failures. In combination with an enhanced touch recognition we expect that the usability of the proposed can be easily enhanced to reach at least the level of current interfaces. This assumption is also based on the subjective feedback from both experiments.

The overall subjective workload analysis using the DALI questionnaire shows similar results for traditional and multimodal interaction and no statistical significance can be reasoned. However, the multimodal approach performs significantly better with regard to the DALI dimensions of manual and visual demand. The reduced visual demand is an indicator that the approach facilitates keeping the eyes on the road which is also confirmed by subjective statements of the participants. Similarly, the reduced manual demand could help to better maneuver the car since less manual interaction is required. We see that the auditory demand is higher for the multimodal approach. Since the traditional approach did not include any auditive components, an increase was expected.

5.6 Summary and Conclusion

Inspired by several important design principles for interactive systems (learnability, visibility, granularity, and easy undo), we implemented a new multimodal interaction style to be used for automotive user interfaces. In its current form, this interaction style combines simple speech commands and minimal touch gesture input on the steering wheel, but it could easily be extended with additional modalities such as midair gestures, or gaze interaction.

While similar with regard to driving performance and workload, the multimodal approach performs better with regard to the visual and manual demand compared to interacting with traditional controls. A big advantage is also the flexibility of the approach that facilitates the integration of additional functions and features. The interaction style is that offers the users a simple starting point for voice interaction in the car.

As future work, it will be of interest to see how well this approach performs to interact with abstract objects and functions, such as features of the entertainment system, including radio stations and navigation. These are features where users would like to use the interaction style as well. Since they do not have a visible physical manifestation, this could, however, lead to a situation where naming these objects is more difficult, as the users may require learning and remembering them.

The interaction style can easily be extend by additional modalities, in particular gaze and body posture, or midair gestures. It is of interest to see how these modalities affect the disambiguation of interaction objects in the car and expect an increased performance. Using eye-tracking technology, another experiment could investigate how the driver's gaze behavior changes when interacting multimodally in order to allow for an in-depth assessment of the visual demand.

Especially for the use case of automated driving and non-driving-related activities, the proposed multimodal approach is of specific interest as it provides a multitude of interaction opportunities. Since the interaction takes place on the steering wheel, this approach is expected to be beneficial also for situations where the driver needs to take over control again. In such a situation it may beneficial if the hands are already on or close to the steering wheel, which is the case with our approach. One idea with this regard is to allow additional activities on the steering wheel during automated rides. For instance, visual content could be presented on the steering wheel touchscreen, similar as proposed by Döring et al. (2011).

IV

Non-Driving-Related Activities

Chapter 6

Context-Enriched Communication

The worldwide number of cell phone subscriptions has increased from about 738 million users in 2000 to almost 6 billion users in 2011[1]. Thus, today, it is very common for cell phones owners to be available at any time. On the one hand, permanent availability offers many benefits to the user. On the other hand, people experience situations where the use of a cell phone is inappropriate (e.g., at a movie theater) or even dangerous such as in the car where communication distracts from the driving task.

Among the non-driving-related activities performed in the car, communication with the outside world, especially through text messages and phone calling, is one of the most frequently performed tasks since the early rise of mobile phones. Hands-free kits are integrated into the IVISs of modern cars and provide connectivity functions such as phone calls, SMS, and e-mail to the driver. A reason for this development is the driver's desire to also be connected and available in the car as well (Árnason et al. 2014; Sohn et al. 2008). As revealed by Kun

[1] International Telecommunication Union (ITU): Global ICT developments, derived from time series by country, http://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2012/Mobile_cellular_2000-2011.xls, last access 2015-05-10

and Medenica (2012), drivers may even be willing to look at a screen showing a remote conversant–at least when they are driving on straight road segments.

Calling is a distracting factor with regard to driving and it is known that the risk of a collision is up to four times higher while using a phone (Redelmeier and Tibshirani 1997). Since an increasing number of accidents was observed where the phone had been used just before the accident (ibid.), handheld calling has been prohibited in a variety of countries[2]. In contrast, hands-free calling is allowed in most countries, although studies revealed that the distraction is similarly high (Caird, Scialfa, et al. 2005; Caird, Willness, et al. 2008; Redelmeier and Tibshirani 1997) since the conversation itself is often the distracting part. At least, hands-free calling allows both hands to reside on the steering wheel and thus offer the chance of faster and better lateral control.

Even though the risk of distraction is known and communication limited to certain activities, many drivers still use their phone on the go. One goal therefore is to improve and support this communication in a way that it is less distracting or to support the change of communication patterns towards safe driving. This need especially stems from the real-world observation that prohibiting communication while driving only works to some extent. Additionally, we also see certain positive effects of calling that would get lost if communication is completely banned. This includes the ability to notify someone about a delay arrival time or for remote guidance at foreign places. Also, we see situations where calling on the phone helps to stay awake and prevent fatigue during a long ride: As initially described by the Yerkes-Dodson Law (Reimer, Coughlin, and Mehler 2009; Yerkes and Dodson 1908), the relationship between arousal level and human performance can be described by an inverted U-shaped curve. As a consequence low arousal (fatigue) and high arousal (stress) both impact human performance. Transferring this concept to driving a car, it is of interest to keep a medium level of arousal to achieve optimal performance (Coughlin, Reimer, and Mehler 2011). Already today ADASs facilitate conducting the driving task and it is obvious that fatigue situations will appear during assisted and partly automated driving (Hajek et al. 2013). In such a situation, mobile communication could be used as an additional source of arousal that helps to maintain optimal driver performance.

Summarizing the current situation, our opinion is that calling while driving manually can and should not be banned completely. Nevertheless, we see the need for improving driving safety with regard to communication while on the go. Our

[2] http://www.cellular-news.com/car_bans/ and http://www.iihs.org/iihs/topics/laws/cellphonelaws?topicName=distracted-driving, last access 2015-05-10

approach is therefore to support the person outside of the car in understanding the current driving situation of the person in the car. This shall help the remote person to identify or prevent dangerous situations and act accordingly, for instance by deferring an intended phone call, by terminating an ongoing call, or by remaining silent until the end of a challenging situation.

In contrast to passengers in the car, remote phone callers normally do not know any context details about the driver besides transmitted background noise. To fill this knowledge gap, we want to share driving-related context information or live images with the remote person to create situation awareness and share a passenger-like perception of car, road, and traffic conditions. We imagine two ways to create an awareness of a driver's current situation: (1) By offering abstract descriptions of the current driving situation (e.g., "is driving", or details about location, speed, road type, weather, traffic) the caller outside of the car can get an impression of the situation already before establishing but also during a phone call. (2) A real-time video stream of the road and/or the driver can convey the feeling of a virtual passenger to the caller outside of the car.

As a basis for such car-mediated, context-aware communication in the car, we propose a concept that enables context sharing in the car and we explored the users' expectations and reservations towards this kind of enhanced communication through context and video sharing. We conducted a web survey to investigate how people perceive the idea. As a follow-up activity, we conducted in-depth interviews to gain additional insights and find out about the expectations towards such enhanced communication systems. We found that automatic context and video sharing (without explicit activation by the driver) is less preferred than situation-based sharing. If drivers like the idea of video sharing, they also assume that it would have a positive influence on driving.

This chapter is based on the following publication:

- Bastian Pfleging, Stefan Schneegass, and Albrecht Schmidt (2013). Exploring User Expectations for Context and Road Video Sharing While Calling and Drivings. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 132–139. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516547

In the remainder of this chapter, we will first discuss related work. This is followed by a presentation of our concept to share context and video streams to callers outside of the car. Next, the web survey and the interviews will be discussed in detail. As a last part we draw conclusions and provide guidelines for the introduction of communication systems for vehicles that use our concept of context sharing. For the remainder of this paper, without loss of generality, we assume that the person outside of the car initiates a phone call (referred to as "(remote) caller") and calls the driver of a car (referred to as "callee" or "driver").

6.1 Related Work

Already more than a decade ago, first concepts of distributing context information to (mobile) phones in general have been developed (Milewski and Smith 2000; Schmidt, Takaluoma, and Mäntyjärvi 2000). The idea is to borrow from communication in a social environment where "situation matters" (Schmidt, Takaluoma, and Mäntyjärvi 2000) and where both communication partners take context and situation into account before starting a conversation. The decision whether to start a conversation or not includes aspects related to the importance of communicating at that moment, the relation between the involved parties, the type and length of the intended communication, and whether starting the conversation is socially acceptable (ibid.). Looking at ordinary remote communication, such information is often not available and people instead ask suitable questions at the beginning of a call to be informed about the current context and the appropriateness of the call. To overcome this knowledge gap for mobile communication, Context-Call (ibid.) offered a WAP-based solution that allows the caller to read callee-provided context information. If this information is available, the caller can decide whether to place a call, to leave a voice message, or to hang up. Other context-related concepts exist where the context is not directly shared but instead context information is used to choose the situation when to communicate. Wiberg and Whittaker (2005) proposed a solution to negotiate a good time to call in the (near) future. Other systems let the callee respond to incoming calls either with pre-recorded messages (Pering 2002) or allow to first listen to an incoming call and then playback pre-recorded messages when talking is not an option (Nelson, Bly, and Sokoler 2001). Similarly, the DeDe system (Jung, Persson, and Blom 2005) allows the sender of a text message to choose the context (for instance location or time) in which the message should be delivered.

Since sharing context information may disclose prive information, it is of interest to investigate sharing patterns and privacy preferences with this regard. In a 10-day contextual inquiry with 20 participants, Khalil and Connelly investigated users' privacy preferences and sharing patterns of context-aware phone calls (Khalil and Connelly 2006). They provide a broad overview of related work with regard to context-aware telephony and privacy. From their point of view, context-aware systems can be divided into two groups: (1) those that empower the "phone owner" (i.e., the callee) by sensing and adapting to the current context in order to better handle incoming calls, and (2) those that empower the caller by offering means to reason about the appropriateness of making a certain call. One main finding of their study is that context-aware calling is feasible and desirable as the participants were only available during 53 % of the time. They also found that even privacy-informed users share information in return for useful services and they also provide some application design guidelines. To understand what types of context information should be conveyed to a callers 'awareness display', De Guzman, Sharmin, and Bailey (2007) conducted a four week diary study to find out which information callers considered and which information callees expected their callers to consider when initiating a call. They compiled a set of lessons to support the design of awareness displays. These rules highlight that it is important to provide cues about the callee' physical (current activity?) and social (in a meeting?) availability, to provide more information than location, the callee's current task status, and to be flexible with regard to the granularity of provided information. Finally, they recommend to empower the caller by providing multiple context cues instead of just a compound availability measure.

For automotive environments, several projects investigated the challenge of reducing distraction for remote communication. An early investigation of intervening phone calls in certain situations has been conducted by Manalavan et al. (2002). Using various auditive signals, they provided context information to the remote caller and found that this could induce the caller to speak less. In a second experiment, they found out that the driving error rate which was increased during conversations can be reduced once the caller ceases talking in critical situations. As a follow-up simulator experiment, Schneider and Kiesler (2005) evaluated the effect of a shared traffic display in form of a mirrored low- or high-fidelity driving simulation on driving performance. The idea was to create context awareness for the remote caller during a conversation. Their study suggest that drivers' behavior changes if a caller has access to remote context information. This could be caused by a different amount and timing of speech. As mentioned in their paper, very high fidelity driving situations would be required to investigate these effects further. Also, they did not evaluate the user acceptance with regard to the proposed technology.

Many calls initiated by callers outside of the car end once the caller notices that the callee is driving. Thus, Kern, Schmidt, et al. (2007) invented a prototype that communicated an abstracted calling recommendation ("calling is ok", "calling might be inopportune", "only call if absolutely necessary") to the caller before setting up the call. The current status can either be set manually by the driver ("only call if absolutely necessary") or derived from certain driving parameters. An initial study showed that drivers felt more comfortable when calls were postponed to more suitable situations and that callers took the calling recommendation into account: unnecessary calls were often postponed or replaced by a text message; often the recommendation was ignored in urgent cases. Bischof et al. (2015) developed a prototypical context-sensitive IVIS that aims to balance driving safety and the driver's need for information. Their system filters irrelevant incoming messages to reduce driver distraction and postpones the delivery of messages based on their priority and on the driver state.

With regard to the technological side of providing context information, platforms already allow accessing car-related context information (e.g., Pfleging, Sahami, et al. 2011; Wilfinger, Murer, et al. 2013) and can be used in context sharing applications. First examples of applications appeared on the market during the last years, including Foursquare[3], Google Latitude[4] or Glympse[5] offer the chance to share the driver's location but need to be enabled manually while or before driving and do not necessarily intervene call initiation. Current apps for smartphones such as Auto SMS[6], DriveSafe.ly[7], and Live2Txt[8] allow for instance to silence incoming communication or enable an auto response function where incoming messages are automatically replied with a message that the person is driving at the moment. Also, it is possible to let the device read out loud incoming messages and reply by dictating.

A body of research exists that investigates the effect of calling on driving distraction (e.g. Iqbal, Ju, and Horvitz 2010). To undistract the driver from communication, Lindqvist & Hong developed a context-aware Android app that offers various concepts to reduce distraction, including burden-shifting (caller is pushed to defer a call), time-shifting (delivery time for messages), and activity-based sharing to

---

[3] http://www.foursquare.com, last access: 2015-05-10

[4] http://www.google.com/latitude, now discontinued, last access: 2013-06-10

[5] http://www.glympse.com, last access: 2015-05-10

[6] https://play.google.com/store/apps/details?id=com.tmnlab.autoresponder, last access: 2015-10-20

[7] https://play.google.com/store/apps/details?id=com.drivesafe.ly, last access: 2015-10-20

[8] https://play.google.com/store/apps/details?id=com.call.disconnect, last access: 2015-10-20

reduce driver distraction ("share information for a certain period of time, related to an activity") (Lindqvist and Hong 2011). Their idea is to provide context information to the caller without needing to answer the phone, and to allow communication in appropriate situations. Additionally, their system offers automatic responses, defers message delivery until receiving is appropriate, and allows to send pre-planned messages to people outside of the car. So far, the system has not been evaluated with regard to driving performance and user acceptance. The effectiveness of proactive alerting and communication mediation while driving has been investigated in a study where auditory messages were used to indicate critical road sections and where calls were placed on hold (Iqbal, Horvitz, et al. 2011). The study revealed that interventions positively affected driving with less driving errors. While drivers supported such interventions, callers were neutral.

Summing up previous work, we see that the issue of calling and texting while driving is of high interest among researchers and actual drivers. While a lot of research has been done looking at different ways to investigate and reduce distraction, the idea of streaming real-time video to the remote caller has not been investigated deeply, especially when it comes to evaluating the callers' and drivers' expectations and position about such technology. Also, the callers' and drivers' opinion towards context sharing has not been investigate thoroughly so far. In this chapter, we contribute an empirical basis for investigating these two technology options.

6.2 Concept: Car-Mediated and Context-Enriched Mobile Communication

The main focus of our concept is to supply details about the current driving context to the remote caller as shown in Figure 6.1. This is done in order to reduce the knowledge gap of the remote caller compared to a real passenger. Such information may be shared *before initiating* or *while establishing* a phone call or sending a message but also *during the conversation* itself. We expect this information to be useful for remote caller and driver alike. The main goal is to increase driving safety while still permitting communication in the car. By providing information already before a phone call or while connecting to the driver, we want to make the caller aware of the driving situation and thus (a) enable a better decision making whether it is appropriate to call the driver at the moment, (b) allow for an adaptation to the driving context for instance by reducing the duration of the phone call or adapting the communication to the driving situation,

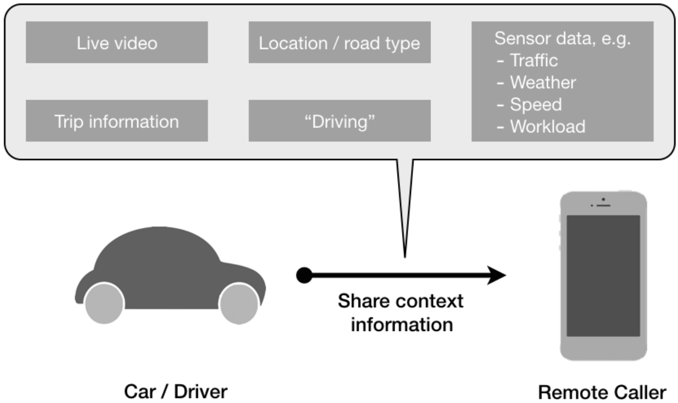


Figure 6.1: Proposed concept to share information of the current driving context with remote callers. By providing different types of data, the remote caller can get an impression of the current context and adapt the communication behavior.

and (c) spare certain calls or messages where the caller is mainly interested in details of the ride such as the time of arrival.

Similar to previous work about context-aware calling, one of our goals is to share context information already before initiating a phone call or sending a message. Our special interest is on driving-related context information of different levels of detail. We also consider the situation of establishing a connection as well as the (phone) conversation itself. During a phone call, the system can additionally stream a real-time video to the remote caller that shows the road or the driver. By showing a live video, various context information such as current speed, traffic, or weather can implicitly be shared with the caller without a need for additional contextual cues. In a way, this would turn the role of the caller into a *virtual passenger*. Such a solution empowers the caller to understand the current driving situation and act accordingly. For instance, in dangerous or challenging situations, the caller could either decide to reduce the call time, hang up, or remain silent until the end of the challenging situation. Similarly, the caller could even warn the driver if necessary or engage the driver in fatigue situations such as an assisted or partly automated ride along an empty and straight highway.

To provide context information to the caller we identified the following details to potentially be shared with a caller as shown in the following list and in Figure 6.1:

Video In order to implicitly transmit context information and let the caller feel like a "virtual passenger", the car could transmit real-time images to the caller. Different transmission types are possible with regard to image representation (high-resolution color image, low-resolution color image, black-and-white image, edge image, e.g., to deal with privacy preferences), frequency (video, still image every 5 seconds, single image on call initiation), and viewing position (front view onto the road, side view, panoramic top view, view to the driver).

Location Before initiating a call, certain location information could be transmitted to the driver such as fine location of the car (exact geographic coordinates), coarse location of the car (for instance the current suburb), and/or the current road type (for instance highway, city road, or residential area).

Sensor data Also, data collected by the sensors of the car including current speed, wiper activity, status of headlights or fog lights, temperature, or the distance to other cars could be processed and shared with the caller to create an impression of the driving situation, for instance to infer the current weather, traffic situation, or time of day.

Trip information Details about the current trip (destination, time to travel, time traveled, number of passengers) can help the caller to identify the current driving situation or find a suitable time when to actually call the driver at a later time. Also, calls to ask about the estimated time of arrival become obsolete if this information is shared automatically.

General driving information If the privacy-concerned driver refrains from revealing private data as mentioned before, this data could be abstracted and summarized. As the most abstract information, the system could reveal to the caller whether the communication partner is driving or not–without having to reveal additional data.

Altogether, we imagine that the proposed system to collect context data is either implemented as an app that runs on the driver's phone or it is installed as an extended hands-free calling kit in the car. Context information can either be retrieved from the sensors that are integrated into the smart phone or using an appropriate interface to access data from the vehicle bus system and sensors (see for instance Pfleging, Sahami, et al. 2011; Wilfinger, Murer, et al. 2013). For video sharing, we assume that a fixed camera will be integrated to the car or one can reuse the camera that might already be installed to detect traffic signs in front of the car. Similar to ordinary hands-free equipment where microphone and speakers of the car can be used by a connected phone, we see the camera as an additional device that can be accessed by the phone. If no hands-free equipment is installed in a car, another cheap solution could be to mount the phone to the windscreen and to use the rear and/or front camera of the smartphone itself. For safety and robustness reasons, an integrated solution should be preferred. If no explicit sensor information is available, an NFC- or Bluetooth-enabled phone could still detect that it is currently used in a car and as a consequence switch to a driving mode. This could be done by using NFC tags or specially designed car mounts with an integrated NFC tag[9]. Once such an NFC tag or a specific Bluetooth device such as the hands-free equipment is detected, this is interpreted as driving a car.

In order to allow the remote communication partner to receive the provided context information, we identified different opportunities. In order to see details about the driving context before initiating a phone call, an adapted phone book application as shown in Figure 6.2 could present this information to the remote caller. Based on the driver's sharing preferences, different details may be visible for each person in the phone book, including symbols for driving/not driving, the current type of road (interstate, regional highway, city road, etc.) or segment (for instance tunnels or low-speed zones), or an image of the driving scene. To facilitate the distribution of such data, one approach is to use a central server where this information is stored similar as it is done with typical messenger applications where the current user status is saved. A similar presentation can also be imagined for apps and messengers to also include this type of communication. Independent of an app that is installed on the remote caller's side, some of the information could also be transmitted to the caller while establishing a connection to the driver. In this case, the app in the car could silently pick up the phone call and use speech synthesis to explain the current context to the caller. The phone would only start to signalize the incoming phone call when the information has been read out to the caller. For text messages, a similar approach to inform the user while sending is feasible. In this case, an approach similar to the one by Lindqvist and Hong (2011) can be employed. We imagine that a message is shown when the delivery process is started. Here, the sender can decide whether to send the message right away or at a certain time in the future, for instance, when the car is stopped or the driver has arrived at the destination. When video sharing has been activated by the driver, an incoming phone call would be replaced by a video call or the video would be streamed through a separate channel to a calling app that is capable of showing

[9] see for instance http://www.cnet.com/how-to/automate-your-android-phone-in-the-car-with-nfc-bluetooth/, last access: 2015-10-20

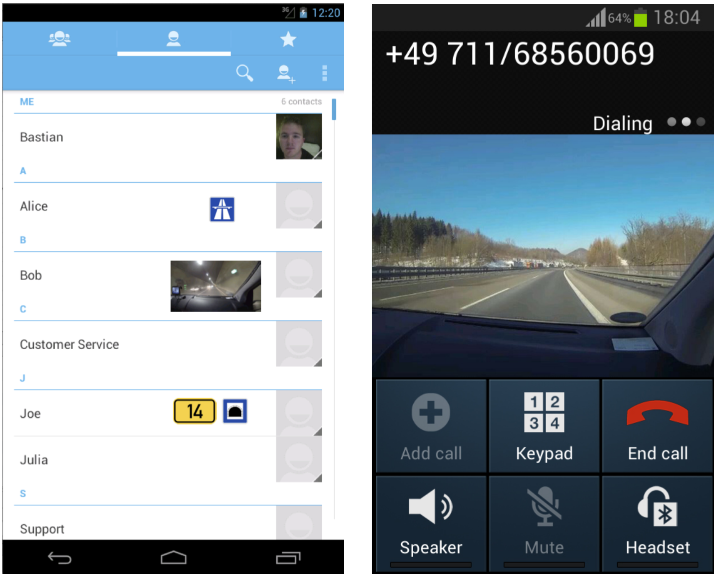


Figure 6.2: Mockup of a context-enriched Android phonebook and calling app: Details about the driving situation can be shared with a remote caller in real-time. Before initiating a phone call, information (possibly at different levels of detail) can be provided in the list of contacts (left). While the phone call is active the idea is to share a live video of the driving situation (right).

the video stream. Figure 6.2 shows an exemplary mockup of such a video-enabled communication app.

In order to respect the driver's privacy needs, various concepts are possible to adapt to the specific needs of a driver, including those discussed in the related work section. A simple solution is to allow the driver to enable and disable context sharing completely. Another approach is to provide the opportunity to define different caller groups and adjust the sharing preferences for each of these groups. One possible distinction could be done using the following grouping which use throughout this chapter: (1) close family members, (2) family members, (3) close friends, (4) friends, (5) colleagues, and (6) other callers. Finally, the driver could spontaneously decide to share information while receiving a phone call or incoming message, for instance by pressing a button on the steering wheel. In case of a phone call, speech synthesis is used in a similar manner as mentioned before. Depending on the implementation of the system, the driver's sharing preferences need to be stored on the driver's phone and a central server.

6.3 Web Survey: User Needs

One prerequisite for a contribution to driving safety of the presented concept is that it is actively used by most of the drivers and callers. Also, the solution must fit to the users' typical communication patterns. To achieve this, a user-centered design approach can be helpful to ensure that an implementation fits the users' needs and preferences. With this regard, it is of interest to understand the users' needs, expectations, and reservations of such an environment that share context information of car and driver with remote callers. We investigated these expectations and reservations by distributing and analyzing a web-based survey to potential users.

6.3.1 Method

Design

In order to get a broad overview of the users' (drivers and callers) expectations of context and road video sharing while driving, we set up a publicly available web-based survey. By publicly distributing the survey, we were able to reach a large number of participants. We distributed invitations to participate via e-mail, different Facebook channels, faculty mailing lists, and learning platforms. Our goal was to gain knowledge about current driving and communication patterns and to investigate the drivers' and callers' opinion on sharing context or video while driving. We also asked concrete questions about the way of sharing information and the users' expectations about the impact of sharing context information.

Participants

In total, 123 participants completed the survey throughout a period of two weeks. They were 19 to 58 years old ($M = 27.21$ years, $SD = 8.18$ years). 34 participants were female (27.6 %), 83 male (67.5 %), while 6 participants did not tell (4.9 %). With regard to their level of education, 43.9 % of the participants had a school-leaving certificate, 10 participants finished a professional training (8.1 %), 56 contestants held a university degree (45.5 %), and three participants did not state anything (2.4 %). About 69.9 % of all participants stated that they are currently enrolled as university student. All participants but one owned valid a driving license that allows them to drive a car (99.2 %).

Apparatus and Procedure

The survey was hosted on a publicly available web server of our institute using LimeSurvey[10] to present questions and record the contestants' responses. The whole system was set up in German and thus targeting at German-speaking participants. At the beginning, we displayed an introductory page to inform about the goal of this questionnaire, the investigation of a novel concept for safe communication while driving. Additionally, the participants were informed that their participation is voluntary and that they can terminate, interrupt and resume the questionnaire whenever they like. They were able to fill out the survey without revealing their identity. The participants did not receive any financial compensation. On average, the participants completed the survey in 15:47 min.

By employing the survey, we wanted to investigate both current and future *communication behavior of drivers and remote callers*. Therefore, we first presented a set of questions about the participants' current driving behavior, the use of cell phones, and communication behavior while driving. In the following part of the survey, we (textually) presented the idea of *sharing context information as a driver* and asked about the participants' opinion and willingness to share such information. We also presented the idea of *sharing live images or video streams* to the remote caller and asked about how and when to share such views from the car. Furthermore, we asked corresponding questions with regard to aspects of context sharing and video sharing *from the perspective of a remote caller*. Finally, we asked to respond to optional demographic questions about the participant such as age, gender, and education. A printed copy of the survey is attached in Chapter A.

6.3.2 Results

In the following subsections we present the results of our survey. We start with an evalutation of the (a) drivers' and callers' current driving and communication behavior. Next, we describe (b) the participants' opinions on sharing context information from a driver's point of view and (c) their perspective on sharing live images or videos as a driver. Contemplating the remote callers' perspective, we will provide details about (d) the contestants' position on context sharing as a

[10] https://www.limesurvey.org/, last access: 2015-05-26

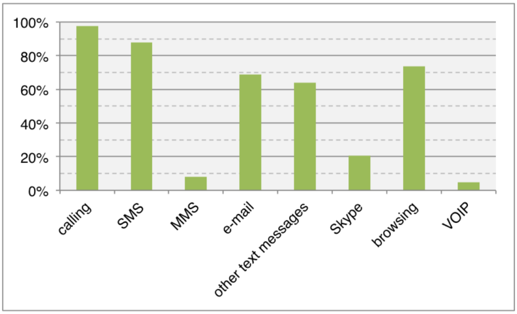


Figure 6.3: Participants' usage patterns for different phone functionalities.

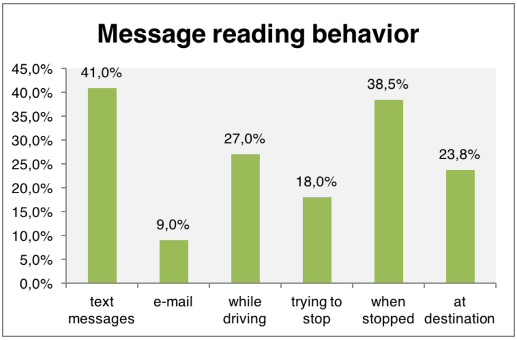
(receiving) remote caller, and (e) their opinion about receiving video streams or images from a car as a remote caller.

Current Driving, Calling, & Texting Behavior

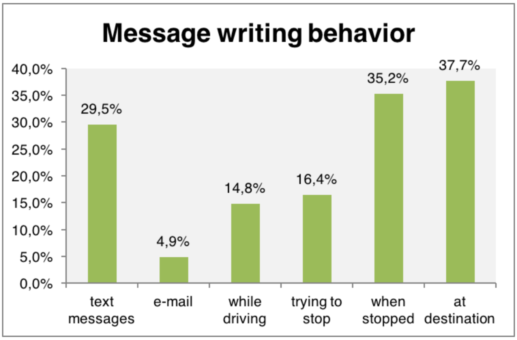
Among all participating drivers (i.e., 122 participants), 41 % used a car almost daily, 2–3 times per week (14.8 %), about once a week (19.7 %), less than once per week (21.3 %), or never (3.3 %).

Most drivers had permanent (51.6 %) or shared access to a car (32.8 %) leaving a 15.6 % of drivers without regular access to a car. If people had at least shared access to a car, we also asked whether their car had some hands-free calling capabilities. In 28.2 % of the cases the participant's car was equipped with a fixed or portable hands-free kit. Speaker phones (17.5 %), headsets (6.8 %), or other devices (1.9 %) were also used to allow hands-free calling. This leaves 45.6 % of cars that were not equipped with any hands-free speaking technology.

When it comes to mobile phone use all participants but one owned either a smart phone (77.2 %) or a traditional phone (22.0 %). Similarly, 76.2 % of all participants used mobile broadband services on their phone. Most of the phone owners used their phones for calling, SMS texting, browsing the Internet, e-mail, or other messaging services; Skype and Voice-over-IP (VOIP) were used less frequently (Figure 6.3). Among all drivers, a third (36.3 %) of the participants never called while driving and another third (32.8 %) did so less than once a week. The rest of the participants used calling while driving either almost daily (9.0 %), 2–3 times a week (8.2 %), or about once a week (13.9 %). Summarized, about two thirds of the drivers use mobile calling while driving a car at least once in a while.



(a) Drivers' message reading behavior in the car (multiple answers permitted).



(b) Drivers' message writing behavior in the car (multiple answers permitted).

Figure 6.4: Drivers' messaging behavior in the car.

For message communication (including SMS and e-mails), we wanted to know whether drivers were reading such messages in the car and in which situations. Figure 6.4a shows that 31 % of the drivers read text messages (SMS) in the car and 9 % of the drivers read e-mails in the car. For all of the questions with regard to message communication multiple answers were permitted. With regard to the situation when such messages are read 27.0 % of the drivers stated to read message while the car is actually moving. 18 % try to stop the car before reading, 38.5 % do so when the vehicle is stopped, and 23.8 % wait until they arrive at the destination.

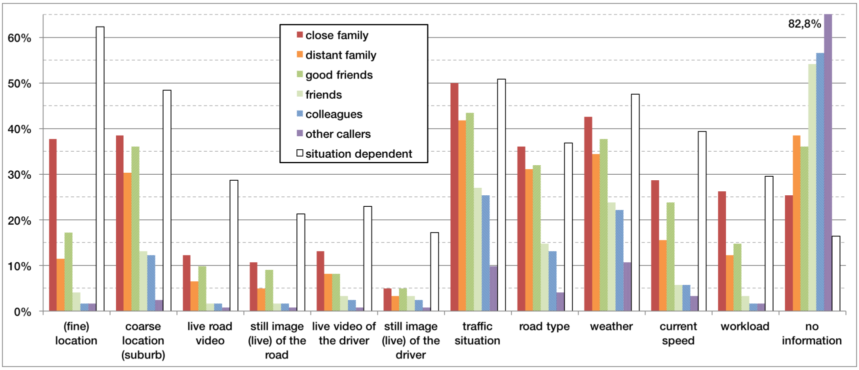


Figure 6.5: Drivers' overall preferences of sharing context information with different caller groups when *automatically sharing* information to these groups (colored bars). The rightmost (unfilled) bar of each data type on the x-axis shows the drivers' *situation-dependent* willingness to share information on a call-by-call basis (independent of the caller group).

We asked the same question with regard to writing messages in the car. Among the contestants 29.5 % state to write text messages (SMS) in the car, 4.9 % do so with e-mails. Surprisingly 14,8 % of the drivers write message while they are driving. 16.4 % try to stop before writing a message, 35.2 % only do so when the vehicle is stopped, and 37.7 % wait until arriving at the destination.

Context Sharing from a Driver's Perspective

To evaluate the drivers' impression about sharing context information, we asked them to imagine that their car is able to share certain types of context information with remote callers such as location, traffic, video or still images, and speed (details see Figure 6.5). As stated before and as visualized in Figure 6.5 we proposed *six different groups of remote callers*: close family (partner, children parents), family, good friends, friends, colleagues, and other callers. We asked the participants about their willingness to share the different information with each of these groups if this information is shared *automatically* for each call. We further wanted to know how their willingness to share such information on a *situation-dependent (call-by-call) basis* is, in this case without distinguishing different caller groups. For each of the groups as well as for the situation-dependent case, multiple information types could be selected.

As shown in Figure 6.5, the most frequently *information shared automatically* would be the current traffic situation (close family 50 %, family 41.8 %, good friends 43.4 %, friends 27.0 %, colleagues 25.4 %) as well as the current weather conditions (close family 42.6 %, family 34.4 %, good friends 37.7 %, friends 23.8 %, colleagues 22.1 %) and the current road type. With regard to the exact location, 37.7 % of the drivers would automatically share their fine location with their close family, it would only be shared by less than 17.2 % of the drivers to callers of the other groups. The coarse location (e.g., the current suburb) would be shared more frequently among family and good friends: close family 38.5 %, family 30.3 %, good friends 36.1 %. Also, some of the drivers would share their current speed (close family 28.7 %, good friends 23.8 %) or workload (close family 26.2 %) with caller groups that have a closer relationship to the driver. The remaining context information types would be shared by less than 20 % of the drivers. Looking at the sharing preferences across all context information types, we observed the highest sharing frequency for the caller group close family, followed by good friends, family, friends, colleagues, and other callers (lowest).

Comparing the preferences of automatic sharing with those of the situation-dependent case (unfilled bars in Figure 6.5), we see a higher tendency to share information based on the current situation across all mentioned context information types. In this case, between half and two thirds of the drivers would eventually share their fine location (62.3 %), traffic situation (50.8 %), coarse location (48.4 %), or weather (47.5 %) information. Also, current speed (39.3 %), road type (36.9 %), workload (29.5 %), live road video (28.7 %), live video of the driver (23 %), or still images of the road (21.3 %) might be shared from time to time.

As we assumed that there might be differences with regard to the driver's willingness to share information based on their driving behavior, we also compared how sharing frequencies differ between drivers that drive almost daily and those that drive less frequently. We found that the willingness to share fine or coarse location, traffic situation, and road type is slightly higher among those drivers that drive less frequently. In contrast, the willingness to share videos or images, weather, and workload is slightly higher among frequent drivers.

Similarly, we compared the groups of drivers that frequently call while driving (at least weekly) and those who call less frequently. The results are similar to the comparison before, but showing slightly larger differences for fine location and workload.

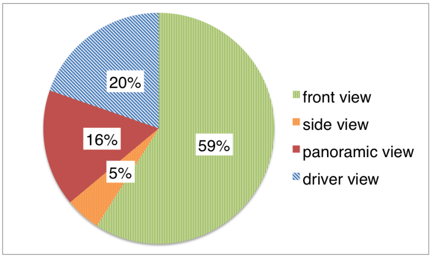


Figure 6.6: Drivers' preferences for camera perspectives to be shared with remote callers.

Video Sharing from a Driver's Perspective

In order to not bias the participants with regard to their preferences of sharing a video while driving, we did not tell them about the potential benefits of our intended concept of sharing context information and videos with remote callers. As depicted in Figure 6.5 the drivers' willingness to *automatically share a real-time video* of the road or of the driver is rather low. Only for close family members, some drivers would share a video of themselves (13.1 %), a video of the road (12.3 %), or a still image of the road (10.7 %). If the drivers can decide to *share a video on a call-by-call basis* instead, we observed a higher acceptance rate: 28.7 % of them might share a video of the road, a video of themselves (23.0 %), or a still image of the road (21.3 %).

In addition to the general video sharing preferences, we asked the drivers about how they would like to share live images with their callers. With regard to the *frequency of images* sent, the drivers would prefer to send a live video stream (17.2 %) over sending a still image every 10 s (4.1 %), a still image on call establishing (16.4 %). The rest would not send images at all (62.3 %). Most of the drivers (95.6 %) had the feeling that sending video images affects their privacy. Two thirds of the drivers would like to choose the *camera perspective* for each individual call. For the general preference of a camera perspective, 59 % of all drivers would prefer to send videos from a front perspective (through the front screen) to their callers (Figure 6.6).

Context Sharing from a Callers' Perspective

When calling somebody's cell phone, 74.8 % of the participants would like to know if the callee is currently driving a car. In contrast to the low drivers' willingness to automatically share information while driving, we see a higher interest in knowing

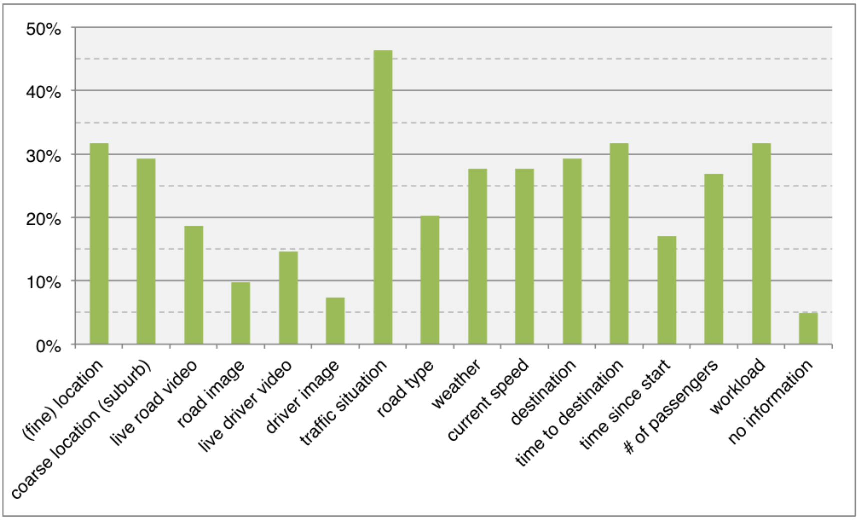


Figure 6.7: Remote caller's interests in getting to know specific context details of drivers on the road.

certain context information when calling somebody who is currently driving (Figure 6.7). Similarly to the question about sharing from a driver's perspective, the participants were able to select which context information they would like to know. The information of highest interest is the current traffic situation (49.9 % of all participants) followed by exact location, time to destination, and workload (31.7 % each).

With regard to the way the information is presented (multiple responses were possible), the callers preferred icon+text (43.9 %) over icon (26.6 %), text or image+text (25.2 %), image (24.4 %), video or video+text (17.9 %), and spoken information (14.6 %).

If the caller receives the information that the driver is currently in a challenging situation, 27.7 % of the callers would not call or hang up, while 23.6 % would defer the call until arrival or until the situation improves (20.3 %).

Video Sharing from a Callers' Perspective

To investigate video sharing from a remote caller's perspective, we asked several questions about how a video should be presented to the caller. With regard to the

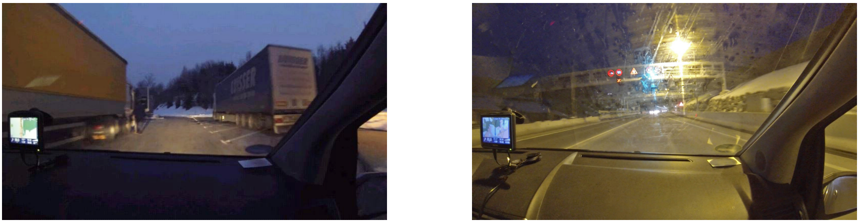


Figure 6.8: Example driving scenarios that have been shown during the interviews to demonstrate our concept of video calls while driving: (a) Leaving a highway resting area. (b) Single-lane tunnel entrance on a highway at night.

frequency of images sent, the callers prefer to see a live video stream 29.3 % over receiving a still image on call establishing (10.6 %), or seeing a still image every 10 s (10.6 %). The rest does not like to receive images at all (39 %). As a *camera perspective*, the front view is preferred most (46.3 %), followed by panoramic view (26.8 %), a view of the driver (24.4 %), and a view through the side window (2.4 %).

6.4 In-depth Interviews

The web survey already provided many details about the users' sharing preferences and their opinion on the use of systems that share context details. Beyond these results, we wanted to investigate how individuals respond when they are closer exposed to the idea of context sharing. In order to do so and to get additional subjective feedback about sharing and video streaming, we conducted in-depth interviews to investigate details about callers' and drivers' sharing preferences and how they would like to use context sharing with remote callers.

6.4.1 Method and Participants

We collected details about drivers' sharing preferences by conducting semi-structured interviews of about 30 minutes per participant. The participants received 5 € as financial compensation. In total, nine participants aged between 25 and 57 years ($M = 36.2$ years, $SD = 11.6$ years) took part in the interviews. All of them owned a driving license and drove at least multiple times a month up to 20,000 km per year. With regard to calling or texting while driving, three of them reported that they regularly phone while driving and another two participants stated that they only talk on the phone while driving if they receive a call.

Procedure

During the interview, we first introduced our proposed idea of video and context sharing while calling and driving. We did so by showing sample videos of driving situations to the participants. These videos were examples for those that a remote caller would see when calling a driver and using the proposed technology. Figures 6.2 and 6.8 provides exemplary screenshots of these videos. The videos were pre-recorded using a GoPro Hero 3 Black[11] camera that was mounted to the front screen of a car in order to record different driving situations from a front passenger perspective. In total, four different situations and videos (duration between 28 and 71 seconds) were shown to the participants: (1) Leaving a freeway resting area, (2) single-lane tunnel entrance on a highway, (3) almost empty, straight highway, and (4) narrow and winding alpine road.

Afterwards, we asked various questions about the participants' opinion to such a context sharing system from both caller's and driver's perspective. We further wanted to know how they would assume that such systems have an influence on driving and the driver's privacy and if they would be willing to use such a system.

6.4.2 Results

Looking at why one would share context information or even video data or not, we observed mixed responses. By sharing context information (before calling) "the caller could decide whether to call or not based on the current driving situation": "I would probably only call if I have to tell or discuss something very important if the other person is driving." (Participant 3) Also, another participant noted that sharing a video could help "to assist the driver, e.g., by helping to navigate at unfamiliar places, or by warning the driver if necessary". Taking the current situation into account, the caller could also "adapt the call length to the current driving situation". Another participant stated that video sharing increases the mutual context knowledge as "the caller doesn't need to ask for the current situation any more".

When asked about the advantages of context and video sharing while driving, a lot of participants imagined that such a technology can improve driving safety:

[11] http://www.gopro.com, last access: 2015-10-20

”I can delay a phone call until the driver is in a less challenging situation. I can also remain silenced during a dangerous situation. This way, a part of the responsibility can be shifted from the driver to the caller. (. . .) Information of special interest would be a hint about when calling would be more suitable or I could even receive an automated callback.” (Participant 1)

If context information is presented even before a call is initiated, the remote caller could take this into account: “If I know the driving situation before placing a call, I can decide to defer the call if the current driving situation requires to do so.” (Participant 3) Similarly, another participant noted that such a technology could “cause other people to only call a driver if really necessary”. If a video of the road is shared, this could help the driver to concentrate on driving since the caller can adapt his or her behavior according to the current driving context:

“Video sharing makes the caller feel like a passenger: The caller can see the current situation and gets a clue why the driver might not respond from time to time”. (Participant 6)

"It is cool that the caller can see where I currently am. But the caller also needs to respect if I do not share the current view. The advantage is that I as a driver can show that calling right now is not suitable. This is much nicer than rejecting a call." (Participant 2)

As a potential drawback, one participant noted that “the driver could get annoyed if the caller wants to influence the driving behavior”. Similarly, the video streaming could “make the driver feel like having a real passenger but also feel more stressed”. Another participant wondered “whether providing context information to the caller indeed can help to estimate the current driver workload”. Also, several participants highlighted that the driver’s privacy needs to be taken into account as they might not like to be observed by their callers. "I would like the system to distinguish between family and other participants: My family and especially my child should be able to call at any time. Maybe different rules apply throughout the day while working and if I am on a private trip." (Participant 1)

Therefore many participants proposed that the system should offer ways to disable/enable context sharing - either on a call-by-call basis, as a “main switch”, or based on user-defined categories (e.g., taken from the driver’s phone book). As mentioned by a participant, the “benefit of video sharing could [also] get lost if the caller just ignores the video”.

6.5 Discussion and Limitations

Summarizing the web survey and the interviews, we see a diverse image of sharing context information and video streaming while driving. Considering the driver's opinion, the motivation to automatically share information is lower than expected. However, one needs to note that this relates to a system that the participants are not yet able use. We see a relation between the degree to which a remote person is known to the driver and the willingness to share context information: The less familiar a caller is to the driver, the less context information would be shared. The drivers would mainly share context information with closely related people (family, friends). Even in this case, only less than half of the participants would like to share context information as a driver.

If we look at the willingness to share when the decision is made just before a call (situation-based), we see in contrast a higher acceptance across all context categories. Altogether, this shows that the participants are rather privacy aware and that the acceptance of such context sharing systems depends on the situation and the user. It seems to be challenging to create acceptable default settings. In combination with the findings from our interviews, this leads to the conclusion that for future context-sharing systems it is very important to offer suitable privacy control and customization means to the driver, which is also in accordance with prior work (Khalil and Connelly 2006). Some of the highest acceptance rates were found for sharing the traffic situation. Compared to other information types as video stream or exact location, the traffic situation abstracts much from the actual driving situation and therefore potentially ensures a certain level of privacy to the driver. Thus, one recommendation for future systems is to offer context sharing on various levels of detail, starting for instance with a very general context information to the caller such as 'currently driving'. This could help to suit different needs with regard to privacy. Additionally, special privacy concerns of the drivers such as preventing the remote caller to store live video streams should be tackled accordingly. As situation-based sharing was preferred over automatic sharing, future systems should investigate different sharing concepts that support the drivers' desire of situation-based sharing.

Looking at the caller's perspective, three quarters of the participants would like to receive some kind of context information as a caller. In combination with findings of the interviews, we see both a high interest of the caller as well as various benefits for the driving situation as the caller gets more insights of the current situation. This is especially interesting for sharing video streams or still images to the remote caller. In order to not bias the participants of the survey, we prevented explaining potential benefits of our concept. In contrast, when talking more detailed about potential context sharing systems as we did in our interviews, the participants recognized the potential value of such systems for driver and caller. Therefore, one of the main challenges will be to communicate the values (for both sides) to the users.

Khalil and Connelly (2006) describe in their work on (general) context-aware telephony, that users will disclose their context information in exchange for useful services. In their study with an implemented context sharing system, they found that such sharing is feasible and also desirable. As they also outline, even privacy-concerned users share as much information as possible without compromising privacy. Their findings are encouraging and lead to the assumption that similar results can be expected for sharing information of a ride as well once an appropriate technology is deployed.

The need for methods to increase driving safety is underlined by some of the facts that we found during the analysis of current communication behavior. Two thirds of the drivers use their phones at least every now and then while driving and an astonishing number of drivers reads text messages while maneuvering a car (27.0 %) or even composes new messages as a driver of a moving car (14.8 %). A similar representative survey on intelligent mobility in Germany that was published shortly after the release of our survey even concludes that a higher number of drivers perform reading (45 %) and texting (21 %) while driving (ARIS 2013). Since we know the distracting influence of communication while driving manually, we see a high potential for solutions that create an awareness of the driving situation as s a stimulus to change communication behavior.

The web survey and the in-depth interviews allowed us to explore in detail the drivers' and callers' positions on context and video sharing while driving. However, some aspects still remain to be explored. One limitation is that the survey has only been published in German, restricting the audience to German participants. It will be interesting to investigate if sharing preferences differ between countries. Also, we are aware that the results mostly reflect the position of users who were not yet able to experience the proposed concept in real life. Therefore, it will be of interest in future work to investigate how an implementation of the proposed concept affects the users' opinions and whether the demand for and use of such systems is perceived. Once the system is in use, it needs to be observed whether context sharing changes usage patterns or the content of communication towards better driving. Also, the effectiveness on the driver's side needs to be monitored. Since context sharing could lead to less driving time being used for communication, it is of interest how drivers will deal with the saved time.

6.6 Summary and Recommendations

In this chapter, we presented a concept for drivers to share driving context information with a remote communication partner. The goal of sharing context data is to make the remote partner aware of the driving situation and react responsibly. So far, the remote partners often know only little about the driving context which in term prevents them from reacting similar to a passenger. Drivers frequently communicate with the outside world even though the risk of being distracted while driving with no automation is known. With this regard, context sharing is seen as a means to help changing the communication behavior without prohibiting communication - for instance by limiting or deferring calls and messages, or pause during a phone call.

One part of our concept is to share different types of information before and while starting a communication. In this phase, facts about the driving context can be provided at different levels of details, from an abstract information that the driver is in the car to details about the current road or location. As a second part, we imagine that driver and remote caller can share a live video stream of the road to the remote caller. By watching the video, the caller can immerse into the driving scene like a passenger and thus react more appropriately to the driver's current demand.

For our concept of context sharing, we investigated the drivers' and remote callers' perspective and preferences toward revealing or receiving context details by employing a web survey and in-depth semi-structured interviews. For overall context sharing, we currently see a diverse image of user preferences. Especially from a remote user's perspective, such information was rated as very valuable. Based on these preferences, we extracted the following conclusions and recommendations:

- **Sharing mode**: Overall, acceptance of automated sharing of context information was less preferred by drivers than situation-based sharing. In order to increase the acceptance and usage of context sharing, it is thus important that these enable spontaneous sharing of information with communication partners.

- **Selection of content to share:** We found a difference with regard to what is shared with the outside world. In general, the more abstract the information was (e.g., only the traffic situation or that the person is driving), the higher was the willingness to share such information. This underlines the privacy-awareness of the participants. Therefore, future systems should provide customization features. They should allow to share information on various levels–from abstract facts (e.g. “driving” / “not driving”) to very detailed facts such as the current location or name of the road.

- **Sharing with different audiences and customization:** Driver’s preferences to share driving context information differed between audience groups. The more a person is known to the driver, the more information the driver is willing to reveal. As a consequence, communication applications should provide easy means to define different audience groups and customize what is shared with each group. This also includes methods to assign individual people into the different groups.

- **Video sharing:** Drivers were still rather reserved towards the concept of sharing a live video of the driving situation. We assume that this will change once they get used to such a system. This is also supported by the experience of the interviews where the participants showed a higher willingness to share video streams. Independently of this, video sharing should not only account for the previously mentioned items, but also for the following aspects: The driver should be able to select whether to share a live stream or still images. Also, it should be possible to allow the driver for each call to share video or not–similar to current messengers such as Skype[12]. As a camera perspective, at least the front perspective should be provided as it was preferred most by the drivers.

The presented concept of sharing driving context information with the outside world is one attempt to reduce the demand for communication, create awareness about the current driving context, and ultimately to increase driving safety. Investigating the drivers’ and communication partners’ preferences is only a first step. As a next step, it would be helpful to plan a large-scale deployment of a specifically crafted app that implements the recommended sharing features. This will potentially involve two separate components. On the one hand, a service on the driver’s phone needs to detect the driving situation along with all context details and for instance forward this situation to a central directory. On the other hand, the remote caller’s system needs communication applications, such as the phone book or the calling app, that will then connect to the same central component and display the information accordingly.

In the form of a (mobile) “research in the large” approach (Henze and Pielot 2013; Henze, Pielot, et al. 2011), an integration of additional means to analyze communication behavior would allow for a detailed analysis of how the delivery and

[12] http://www.skype.com, last access: 2015-10-20

presentation of context information changes the behavior when communicating with a driver on the road. As one example different presentation formats (e.g., icons shown in the contacts list or a spoken information while the call is initiated) could be compared in such an experiment with regard to their effect on number of phone calls made or deferred, or the length of phone calls.

The chances for mobile video communication (in the car) were limited with regard to network coverage and especially network speed until recently. With the introduction of high-speed mobile networks, for instance base on LTE technology, it is now possible to also stream videos using a higher bandwidth in many parts of the world. Thus, another experiment could be performed to investigate the effect of road video sharing on the driver's and remote caller's communication behavior as well as the acceptance of such approaches when used "in the wild".

Chapter 7

Time-Adjusted Media and Tasks

In 2013, individuals in Germany spent on average 84 minutes per day for transportation (Streit et al. 2014), including purposes such as going to work/home, leisure, shopping, and education. 46.5 % of this time, i.e. about 39 minutes of the transportation time was spent on motorized individual transportation, i.e., in cars and on motorized bikes (ibid.). For the Unites States of America, this average transportation time in a private vehcile was about 56 minutes in 2009 (Santos et al. 2011). As mentioned before, people use this time already today to perform various NDRA while driving, using either technology integrated into the car (e.g., the IVIS), nomadic devices (e.g., smart phones and tablets), or other devices and objects (e.g., newspapers, food, beverages, or cigarettes). Besides personal communication as discussed in the previous chapter, especially all forms of entertainment, work-related issues, and leisure/relaxation are of interest to the driver, especially since most of the time in the car is spent alone.

Many of the activities are performed while the vehicle is in motion. During these phases especially activities that required the driver's visual attention such as reading or watching videos are less recommended or even prohibited to use, either by law or as enforced through guidelines and standards as outlined in Section 2.5. The main reason is that visual content such as videos or longer pieces of text require the driver's visual attention and distracts the driver. That's why especially audio entertainment through radio, CD, MP3 playback, or streaming technologies is commonly used today. Auditive output–often perceived rather ambient–does not affect the driver's visual attention but demands other resources of the driver such as the auditive channel. But it allows the driver to keep the eyes on the road. However, we see an increasing trend of providing display hardware such as the central information display (CID) or fully digital dashboards in the car that may not only present rather static but also dynamic visual content. These screens are capable of displaying content such as text, videos, emails, or even allow to play games.

Perceiving or engaging with visual content in the vehicle significantly differs from doing so in stationary settings such at home or at work. Yet, traditional content still prevails inside vehicles. We believe that the type of content shown on such screens has a strong influence on the perception and hence the degree of distraction from the driving task. This is due to several reasons: first, the driver's attention is taken off the road and focused on the screen. Since the display is often not aware of the current driving situation, it cannot provide any indication when the attention of the driver should be directed back towards the road. Second, content such as television programs, movies, and also games are in general not suitable to be (entirely) perceived in very small time frames.

Already today in many situations no or only little of the driver's (visual) attention is required: Examples include waiting at traffic lights, in front of a railroad crossing, or standing still in a traffic jam. In such a situation, the driver only needs to make sure that the vehicle is not moving and to start driving again when the situation permits, or react and make room to emergency vehicles. Employing the example of the traffic light, often the waiting time or time to intervention (TTI) is known. Similarly, for future (fully) automated driving, the planned time until a handover to assisted or manual driving may be known as well. While driving on a highway that permits fully automated driving, this TTI could for instance be the time it takes to reach a certain exit of the highway, i.e. the location where manual driving has to start again.

Employing the car's context information–especially location and the time to intervention–we explore in this chapter how to enable time-adjusted activities while (almost) no attention of the driver is needed to drive the car. The idea is to adjust multimedia content or other NDRAs in a way such that (a) the length of the content can be tailored to the available time, i.e., the TTI, while the car is standing or for instance driving fully automated, and (b) the attention of the driver can be directed back to the driving scene just when it is required. The focus of this chapter is on the concept and technology to pave the way towards an enabling infrastructure for time-adjusted NDRAs. The contributions of this chapter are: (1) We present a model on how to enable time-adjusted NDRAs in the car. (2) As a case study, we investigated how this concept can be used to entertain the driver while waiting at traffic lights. For this case study, (3) we report on the findings from a web survey among 127 participants on the potential of micro-entertainment and time-adjusted NDRAs. Furthermore, (4) we present an algorithm, which identifies zones in front of traffic lights and associates an average waiting time depending on data obtained both from former encounters and other vehicles. Finally, (5) we present a prototypical implementation and a qualitative evaluation of the enabling technology.

This chapter is based on the following publication:

- Florian Alt, Dagmar Kern, Fabian Schulte, Bastian Pfleging, Alireza Sahami Shirazi, and Albrecht Schmidt (2010). Enabling Micro-Entertainment in Vehicles Based on Context Informationm. In: *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '10. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 117–124. ISBN: 978-1-4503-0437-5. DOI: 10.1145/1969773.1969794

7.1 Related Work

As already outlined in Chapter 2 (Background and Related Work), in-car entertainment has already a long tradition which goes back to the 1920 s when the first commercial automobile radios entered the market. Nowadays in-car entertainment includes different communication and entertainment channels and displays, hence providing a similar set of information as it can be found in home entertainment. In the following we report on entertainment in cars, available sensors and their applications, and car communication.

7.1.1 Entertainment and Information in Cars

In vehicles, different devices are used to convey information via various communication channels. Most popular devices, such as radios and CD players, mainly use the audio channel hence limiting the distraction of the driver. Content includes music, news, audio books, ads, and traffic information. Mobile phones, often connected to a cars' internal speaker systems via Bluetooth, do not only allow for interpersonal communication but also provide a convenient way of connecting to the Internet. This enables access to up-to-date traffic information, emergency services, and emails. Furthermore, multimodal displays also allow for showing video content via DVB-T, Video on Demand, or DVD. However, in many countries law permits the perception of video content while driving. As a result, displays are often integrated in the headrest of front seats, providing content to passengers in the back seats only. As an alternative, Mercedes offers a concept called SPLITVIEW[1], where a single screen as CID is overlayed with a mask to produce different images for driver (i.e., only static content) and passenger.

The need for entertainment has been identified in different surveys investigating mobility, connectivity, and entertainment. Regarding communication this has already been outlined in the Chapter 6. In Germany, this was investigated in two consecutive and representative surveys (> 1000 participants, aged 18 or 14 and older) about intelligent mobility, communication and digital navigation, and e-mobility (ARIS 2011, 2013). When asked about which Internet-related applications are relevant in the car (in 2011), the most important topics were related to navigation and points of interest (39-18 %), followed by business e-mails (17 %), Internet radio (14 %), personal e-mails (14 %), communication such as Skype (6 %), movies (5 %), online driver's logbook (4 %), and gaming (3 %) (ARIS 2011). The low numbers for certain aspects of entertainment probably relate to the fact that advanced driving assistance was still in its infancy and that the use was not specifically related to suitable situations as proposed for our concept. Two years later, 23 % of the drivers expect cars to be connected to social networks, 22 % want to read or write (11 %) e-mails (ARIS 2013). Towards the support of assisted driving, 82 % of the contestants expect future cars to offer more entertainment than just music from the integrated radio even though 54 % of all contestants also acknowledge that (current) multimedia systems distract the driver (ibid.). Thus, we see an importance gain of entertainment and productivity functions, especially towards assisted and automated driving.

Related work about in-vehicle entertainment often focuses on the passengers. Whereas Laurier et al. (2008) reported on what people do while traveling in general and together, different research projects have investigated the use of in-vehicle infotainment systems. Alt, Shirazi, et al. (2009) implemented a context-based entertainment system by using a cab's context information to provide adaptive contents. Palazzi et al. (2007) presented an approach to deploy a distributed online

[1] http://techcenter.mercedes-benz.com/en/splitview/detail.html, last access: 2015-06-10

game based on multi-hop vehicle-to-vehicle communication, allowing for a shared user experience among travelers on the same road. To entertain children in the backseat, Gustafsson et al. (2006) presented a context-aware storytelling game that aims to creating a narrated experience for children.

For passengers, especially on the rear seat, watching videos or performing other entertaining activities on nomadic devices or fixed rear seat entertainment systems is done for different purposes and audiences such as business passengers and kids[2] (Tester, Fogg, and Maile 2000; Wilfinger, Meschtscherjakov, et al. 2011). As outlined by Wilfinger, Meschtscherjakov, et al. (2011), automotive research did not focus too much on passenger and rear seat entertainment even though novel findings might provided beneficial implications for the interaction design. Since the focus of this thesis is to support NDRA for the driver, we will mainly discuss entertainment aspects as long as they are relevant for the driver in this chapter.

CommuterNews is an early prototype of a persuasive IVIS that aims at engaging the user into interaction with the system (Tester, Fogg, and Maile 2000). Instead of presenting typical news stories it presents short sound clips as well as related multiple-choice questions to the driver. Using an in-vehicle Internet browser and assessing the different control devices was investigated by Kamp et al. (2001). Funkhouser and Chrysler (2007) assessed the impact of in-car video entertainment on the user behavior and driver distraction. Bader, Siegmund, and Woerndl (2011) investigated the user acceptance of proactive in-vehicle recommender systems in the vehicle with regard to navigation and search for points of interest. Following our initial approach for time-adjusted media consumption, Rosario, Lyons, and Healey (2011) present a natural language processing system that tailors synthesized text content for the driver. Based on predictions for time spans with low demand, text is summarized for this time and dynamically re-summarized when interrupting events happen.

Árnason et al. (2014) summarize the challenges with regard to in-vehicle infotainment as "*what* to present, *when* to present it, and finally *how* to present it" (ibid.). In their paper they present a multimodal proactive recommendation system that presents personalized content and uses sensor information to decide when to present content to the driver. In the content domain, they differentiate between efficiency (e.g., handle e-mails, enter GPS locations), entertainment (mainly music and movies), information (news), and social (social networks).

[2] https://www.abiresearch.com/market-research/product/1018882-rear-seat-automotive-infotainment/, last access: 2015-06-01

7.1.2 Sensors in Vehicles & Car-to-X Communication

Most modern vehicles comprise a variety of sensors such as accelerometers, distance sensors (including radar), cameras, or gyroscopes. These sensor provide access to information inside and outside of cars and their data is mainly used to support and enhance the primary task in the car and to assist the driver (Gharavi, Prasad, and Ioannou 2007; Jones 2002; Russell et al. 2002). Prominent examples are parking assistance systems and night vision systems (Tsuji et al. 2002) among the multitude of assistive systems outlined in Chapter 2. The GPS system allows to determine the exact position of a car. Car navigation systems us this information in combination with map data to enable route planning and guidance. Often, these systems are also able to obtaining traffic information in order to improve the arrival time calculation. Approaches to integrate traffic information include both offline systems (routes are calculated based on previously collected traffic information and navigation data, e.g., TomTom IQ RoutesTM) and real-time approaches such as so-called cellular floating phone data systems (TomTom International BV 2009). The latter use the triangulated location of users in a mobile phone network to infer movement data and infer traffic information. Also, additional sources include for instance traffic surveillance cameras and sensors at infrastructure objects that measure floating car data (Rohling 2012).

Car-to-X communication, used as a summarizing term for car-to-car and car-to-infrastructure communication, aims to increase driving safety and enable advanced services by connecting vehicles and infrastructure objects (ibid.). This type of communication aims at increasing safety in everyday traffic, e.g., by providing real-time information for instance on traffic, surrounding cars, hazards, and warnings far beyond what a driver can see (Festag et al. 2008). Moreover it enables applications to improve traffic efficiency and infotainment. Car-to-car communication focuses on information exchange between vehicles, whereas car-to-infrastructure is based on communication between vehicles and fixed stations of the road infrastructure (e.g., beacons for road warnings, dynamic speed signs, or traffic lights). To realize car-to-X communication, different technologies have been proposed with VANETS (Vehicular Ad Hoc Networks) being the most important technology (Boukerche et al. 2008). For such ad-hoc networks, different types of communication exist, for instance to contact a certain car or object (unicast), to notify all surrounding objects (broadcast), or to notify all cars in a certain geographic region (geocast). We refer to the Car to Car Communication Consortium Manifesto (2007) for a comprehensive overview on the main concepts and technical details of car-to-X communication. With regard to our concept of time–adjusted media and tasks, car-to-X communication provides serveral interesting features, including access to traffic details, data about traffic lights, and the chance for an IP-based Internet access (instead of using mobile phone networks) to retrieve any kind of web-based content for time-adjusted activities, such as news, emails, and YouTube videos.

7.2 Concept: Time-Adjusted Activities

Today, people spend a considerable amount of their time in the car in front of red traffic lights, especially in urban areas. Especially when driving alone, users seek for entertainment, for instance by listening to the radio or calling other people. While waiting in front of a red traffic light, drivers also use their mobile devices for example to read the latest news or to read and write messages on mobile devices even though the handheld use is forbidden in many countries as long as the engine is running. Often, a disadvantage of using such technology is that the driver does not notice that the traffic continues until (s)he is notified by the driver behind who is honking the horn. For many intersections, the switching times for traffic lights are pre-programmed and fixed and could be used as TTI by vehicle systems and communicated to the driver. So far, this information is, however, often not accessible and therefore not used for in-car user interfaces.

For the initial phase when highly automated driving is introduced, we expect situations to happen that are similar those when waiting at traffic light: The driver wants to get to a location that has been entered as destination into the navigation system. On this route, only certain segments are suited for highly automated driving, for instance the 30 km-segment of the route on the highway between start and destination. When the length of this segment, the speed limits (of the road segments and the automated driving system), and the current traffic situation are known, the IVIS can estimate the duration of the highly automated driving segment as time to intervention (TTI). During this time, the driver may have the chance to perform additional NDRAs since no attention is required to the driving situation. Similar to the traffic light example, the driver needs to direct the attention back to the driving task shortly before the end of the highly automated driving phase in order to perform the take-over request. In this situation, it is even more important that the attention switch happens in time since the car is in motion and needs to be controlled properly to not put driver, passenger, and the environment at risk.

The concept of time-adjusted NDRAs and media consumption is to provide activities to the driver whose expected utilization or processing time is less than or equal to the TTI (see also Figure 7.1). This approach provides two benefits:

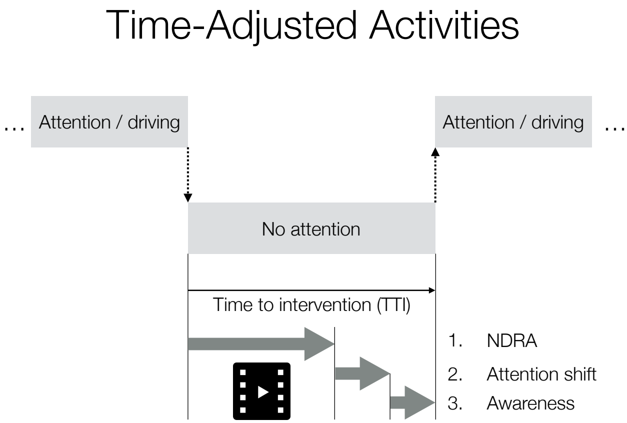


Figure 7.1: Proposed concept for time-adjusted NDRAs. The idea is to offer NDRAs for phases when (almost) no attention to driving is required and when the time to intervention (TTI) is known. The IVIS offers activities with a duration slighly less or equal to this TTI. Thus, the driver can complete the activity and direct the attention back to the road just in time.

(1) By providing NDRAs and especially entertainment in the form of content that is adapted to the standing time we believe that we can enhance the user experience of in-vehicle activities in comparison to traditional content (TV program, DVDs) since they can be performed completely and do not need to be interrupted or resumed at a later time. (2) The system can actively and unobtrusively direct the driver's attention back towards the road. This increases the safety of consuming media or performing other NDRAs while driving. In case of unpredicted events that need the driver's immediate intervention, the currently performed activity would be interrupted and the same methods that are used to warn the driver to perform a take-over request (TOR) would urge the driver to pay attention to the road again, for instance by using visual and auditive warnings (Gold et al. 2013).

In order to implement the proposed concept, in-vehicle systems need to be aware of the TTI. Since we did not yet have access to prototypes of automated vehicles, we only consider the traffic light situation as a first use case in this chapter. For this context, we focused on entertainment activities, that we could also address as micro-entertainment since the time is often shorter than typical periods of media consumption in home environments. We expect that the concept can easily be transferred to the highly automated driving context.

To support the situation when waiting at a traffic light, it is necessary to have access to the waiting time or TTI. While this information could be obtained through car-to-infrastructure communication between the traffic light and the vehicle itself[3] or from local authorities, current approaches often lack standard and are not yet commonly used. Different traffic lights vary with regard to the duration of their red phases and even for the same traffic light often the duration differs depending on the day of the week, the time, or the amount of traffic. Hence we propose a two-step approach to provide entertaining content in a meaningful way. First, we show how to detect, refine, and extend areas in front of traffic lights. Second, we create an estimation of the waiting time for each traffic light enhanced with information of each car approaching. Before describing our approach, we report on the results of a web survey that we conducted to assess the potential of time-adjusted activities.

7.3 Web Survey

To assess the potential of time-adjusted micro-entertainment and to gather initial ideas about suitable representations and content we set up a publicly available web survey that was accessible over 2 weeks in February 2010. We recruited people via mailing lists, from friends, colleagues, and Facebook.

7.3.1 Method and Participants

In total 127 people completed in the survey during a period of two weeks. The participants were aged between 18 and 69 years ($M = 34$ years). 92 contestant were male (72.4 % and 35 female (27.6 %). With regard to using displays to show navigation instructions and/or entertainment content, 40 participants (31.5 %) stated to use a multifunctional display that is permanently installed in a car, 80 participants (63 %) stated to use a portable device for this purpose.

[3] see for instance Audi's Travolution, http://www.travolution-ingolstadt.de/, last access: 2015-06-12

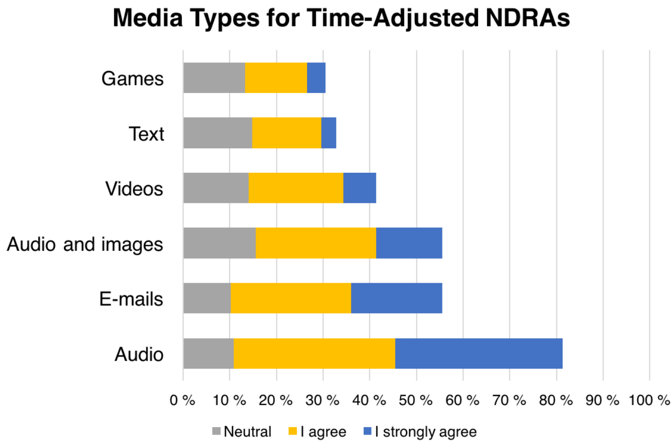


Figure 7.2: Preferred media types for time-adjusted NDRAs (5-point Likert scale from 1: "I strongly disagree" to 5: "I strongly agree").

7.3.2 Results

First, we were interested in the use of displays in vehicles. More than 90 percent of the people use either a fix or a mobile display for navigation or entertainment purpose.

Second we asked the participants on a 5-Point Likert scale (from 1: not useful at all to 5: very useful) which media types would be useful for them, results based on a rating of 4 or 5, see Figure 7.2). More than 70.3% prefer audio, 45.3% would like to read emails, 40% could imagine audio augmented with additional images, and 27% can imagine having short video clips. Short games (17.2%) were rather unpopular. The strong preference for audio content (with and without images) might be the result of an adaption to the use of radio in vehicles. Still, a significant number of people see an advantage in checking their emails. The rather low popularity of displaying text might be a result of the fact that people prefer having a text read out loudly rather than reading it themselves and that writing on a touch screen inside a car is quite cumbersome. Further suggestions from users regarding content include reading and writing SMS, using vocabulary trainers, displaying RSS feeds, blogs, and playing back longer movies. Surprisingly participants stated that they would even prefer to have the movie played back with audio only (black screen) while driving.

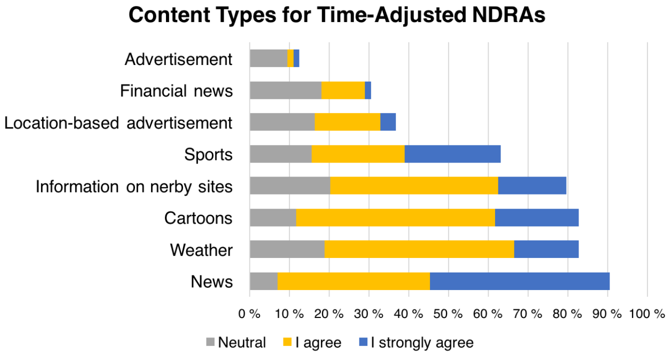


Figure 7.3: Preferred content types for time-adjusted NDRAs (5-point Likert scale from 1: "I strongly disagree" to 5: "I strongly agree").

Third, we were interested in different types of content, participants considered to be attractive (see Figure 7.3). Most popular were general news (83.6%), cartoons (71.1%), weather (64%), and location-based information on points of interest (59.4%). We were also interested in the popularity of showing ads on the screen. Whereas general ads were very unpopular, context-sensitive ads (e.g., related to the car's current location) were considered to be useful by 20.1%. Participants' additional suggestions regarding suitable content included appointments, events, regional traffic information, health, and information on close-by restaurants.

Fourth, we assessed the acceptance of a system, which adapts content to the length of standing times among the participants of the survey. We found out that more than 50% would use or definitely use the system (5-Point Likert scale, 1: "I would not use the system at all", 5: "I would definitely use the system"). Based on open-ended questions we found out that most people see the main value of the application in bridging waiting times or using the time in a meaningful way. Additional reasons included the provision of compact and up-to-date information as well as entertainment. People who were concerned with using such a system stated that they might feel distracted from traffic and that this might pose a potential security risk. Another issue mentioned was that waiting times in front of traffic lights are often too short in order to show meaningful content.

Fifth, we asked people in which situations they would consider such a system to be useful. It turned out that 72.4% would mainly use such a system when being in the car alone, whereas only 16.6% would use it if other persons were in the car.

Further, 58.3% would prefer the system in case they were familiar with the route, but only 24.4% in cases they took an unfamiliar route.

7.3.3 Discussion

The results of the web survey reveal a strong potential of micro-entertainment in vehicles. Whereas audio content is still the preferred form of entertainment, a considerable number of people (more than 40%) could imagine using visual content such as emails, images, or videos in cars. It turned out that content, which could be fit in short time intervals (news, weather, cartoons, etc.), was favored by the participants. When analyzing answers regarding appropriate situations for such a system it becomes clear that commuters would be a primary target group since the majority would use such a system when traveling alone and on familiar routes. Qualitative user feedback revealed that inappropriate length of content would be an issue.

7.4 Case Study: Traffic Light Zones for Micro-Entertainment

In a first step, we identify areas in front of traffic lights, so-called *traffic light zones (TLZs)*. We use GPS information, which allows for applying the approach independent of a traffic light location, the day, and the time of day. We assess how long red phases are based on the standing times of the vehicle. Therefore, we do not even need to know the location of a traffic light beforehand but rather learn it depending on the stop-and-go characteristics of a GPS track. Based on the GPS data we obtain the vehicle velocity in order to determine whether it is moving or not. Since the accuracy of GPS data is not fully sufficient for a precise calculation of position and velocity we use state transitions and a threshold to determine a vehicle state. We distinguish the following states: (1) The vehicle is moving and (2) the vehicle is standing (Figure 7.4).

Standing and moving times are defined as the time between two state transitions. Additionally, we store the direction for each standing point as a tuple, consisting of longitude and latitude (*dir_long*, *dir_lat*). To calculate the correct direction of travel, we consider a reference point, stored at a certain frequency. To create a TLZ we allocate standing points in front of the same traffic light. We do so by calculating the distance between a vehicle's current standing point and

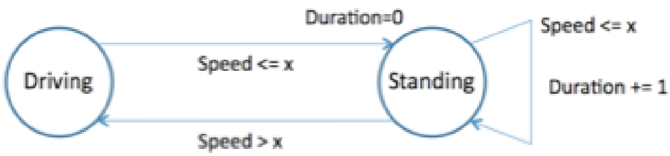


Figure 7.4: State diagram to infer the vehicle status from GPS data.

existing TLZs. For calculating the TLZ we use the following equations based on Pythagoras' theorem[4]:

$$lat = \frac{lat_1 + lat_2}{2}$$

$$dx = 111.13km \cdot \cos(lat) \cdot (lon_1 - lon_2)$$

$$dy = 111.13km \cdot (lat_1 - lat_2)$$

$$\text{distance} = \sqrt{dx^2 + dy^2}$$

To calculate the direction, we compare the longitude and latitude of the reference point with the standing point. In case of a match with the previously stored zone, we assume an equal direction.

7.4.1 Algorithm and Evaluation

Figure 7.5 depicts the algorithm that we used to identify traffic light zones. Once the state changes to "vehicle is standing", we test if a zone exists which lies within a certain distance from the vehicle position. If yes, we also test the direction and in case of a match associate the current standing point with the TLZ, and expand it. Hence, we are able to create also larger TLZs, for instance in front

[4] Note: Whereas for the latitude the distance between two degrees is always 111.13 km, it varies for the longitude, ranging from 0 km at the poles to 111.13 km at the equator.

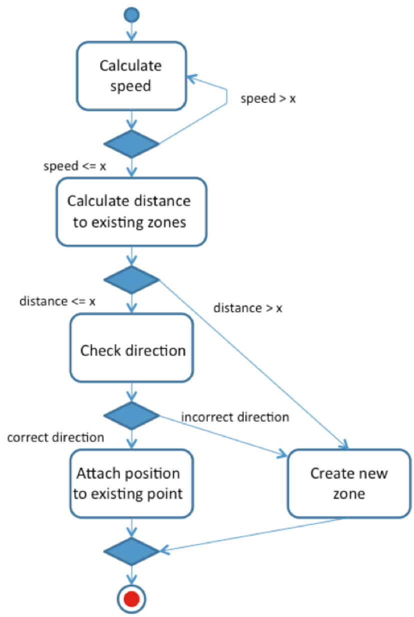


Figure 7.5: Algorithm for the identification of traffic light zones (TLZs)

of traffic lights producing long congestions. In case no traffic light position lies within the pre-defined distance or if the direction does not match, a new zone is created. We use three variables which impact on how precisely TLZs are created and rediscovered.

Velocity threshold The threshold specifies below which value the velocity of a vehicle has to drop for considering it as a state transition. Values between 0-1 km/h hardly occur in GPS devices since the velocity asymptotically adapts to the correct speed. Hence, the velocity after 5 seconds of standing still lay beyond 0.5 km/h.

TLZ size This parameter specifies within which distance to a given zone a new standing point has to lie in order to be considered a part of it. Low values lead to more TLZs, high values might incorrectly identify standing points as a part of a traffic light zone.

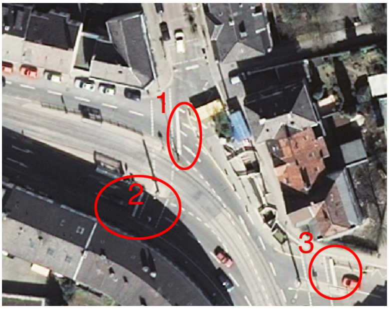
Update frequency of directional reference point for calculating the direction of travel, a reference point is used. This reference point is a previously stored position of the car. The update frequency specifies how often the reference point is stored.

To understand the impact of those variables and to obtain suitable values, we equipped two daily commuters with GPS loggers and had them log their GPS track over the course of 2 weeks. We collected a total of 36 GPS tracks (9 GPS tracks for each participant commuting from home to work and vice versa). We applied our algorithm to the data and tested different values for the size of the zone and the frequency of storing the reference point in order to obtain close-to-optimal results. For an appropriate evaluation, we visualized the results using the Google Maps API. Figure 7.6a shows the correct location of the traffic lights, the obtained results are depicted in Figures 7.6b to 7.6d. Markers represent positions where the first standpoint of a TLZ was defined; polygons represent the enclosing area of the maximum and minimum longitude and latitude values.

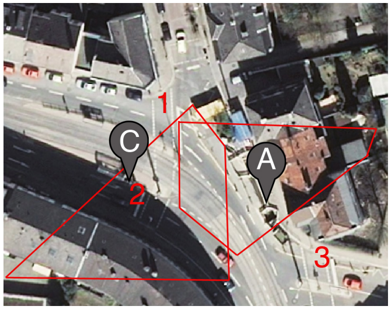
Configuration 1 gives an example where the size of the TLZ is too large. Thus, this specific TLZ size parameter leads to an overlap of traffic lights 1 and 2. Whereas the extension towards the southwest is a result of imprecise GPS data (street canyons) the extension towards the east is a result of the left-turning traffic. Configuration 2 resulted in 5 TLZs. Zones B, F, and A are associated with traffic lights 1, 2, and 3. Zone G represents the left-turning lane of traffic light 2. Zone L is in the same location as the top-corner of C in configuration 1. It is correctly not associated with zone B since this point is approached by northbound traffic. The outliers in zones A (north) and B (south) are again a result of imprecise GPS data. Configuration 3 resulted in 2 zones. Due to the higher update frequency of the reference point the zones around traffic lights A and B are merged, as are left-turning traffic from traffic light 2 and 3. The reference point is too close to the current position.

7.4.2 Results

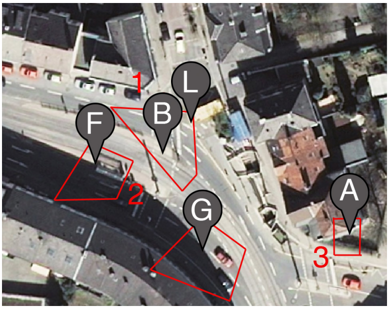
Figures 7.6b to 7.6d show that the size of a zone and the update frequency of the reference point for the direction have a strong impact on the correct association of the points with existing TLZs. In total, configuration 2 (zone size: 30 m, update frequency: 6 Hz) returned the best results. Further tests revealed that a lower update frequency led to wrong results as the probability for changes in the direction increased. We discovered that values below 0.2 km/h generated less standing points and entire zones collapsed. Values between 0.2–1 km/h resulted in



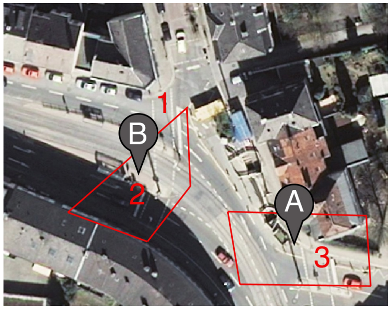
(a) Correct positions (1–3) of the traffic lights



(b) TLZ configuration 1: zone size 50 m, update frequency for reference point 6 Hz



(c) TLZ configuration 2: zone size 30 m, update frequency 6 Hz



(d) TLZ configuration 3: zone size: 30 m, update frequency: 12 Hz

Figure 7.6: Detection of traffic light locations: Figure (a) shows the original locations while the other figures depict the detected traffic light zones (TLZs) based on different configurations of the detection algorithm (Aerial image: Regionalverband Ruhr, CC BY-NC-SA 4.0).

a lower standing time in the zones. An increase in velocity also led to an increase in standing times. A threshold of 1 km/h turned out to be a good compromise.

7.4.3 Discussion

Though we envision our approach to work in most cases we are not able to distinguish between vehicles stopping in front of traffic lights, turning areas, parking lots, traffic jams, stop-and-go traffic, and at railway crossings. Whereas traffic-jams, parking, and stop-and-go traffic only pose a minor issue, all types of stops which are likely to occur frequently are a problem since they might be identified as a traffic light zone by the algorithm.

The presented approach works without the use of existing map material and can thus be used at any location. Today, we see that much effort is put into (public) mapping projects such as OpenStreetMap[5] that collect any type of geographic information. Besides basic objects like roads, rivers, and landscapes these databases are more and more filled with detailed information, including traffic signals[6]. As a consequence, for future versions we imagine an approach where the detection of traffic light locations combines the data of the presented approach with publicly available map data. Ideally, such information is also fed back to the database to reflect potential changes and increase the quality of these maps.

7.5 Estimating Waiting Times

On average, entire red phases last 30 to 45 seconds. However, precise knowledge about the length can be used in various ways. First, content can be tailored to fit the waiting time. Second, drivers could be actively made aware of resuming traffic. For the calculation of the standing time in front of traffic lights we first calculate the mean value X of all previously stored standing times. Second, we calculate the standard deviation s on the variance of all known data. Thus we get as a result an interval $[X-s, X+s]$, which represents the expected duration of the next standing time. In order to avoid that the duration of the clips extends the duration of the standing time we opted to use the interval $[X-s, X]$ in the prototype. The maximum length of the clip was set to $X-(s/2)$ making sure that the clip length neither exceeded nor to a large extent fell below the actual waiting time.

The quality of the approach depends on the size of the dataset. Whereas small samples are likely to produce high error rates, large samples provide a good approximation of the standing time. The value of the standard deviation can be seen as a measure for quality – the higher the amount, the worse is the data quality. To more quickly obtain larger sets of data we store information in a central database hence making it available to all other drivers.

---

[5] http://www.openstreetmap.org, last access: 2015-10-20

[6] http://wiki.openstreetmap.org/wiki/Tag:highway%3Dtraffic_signals, last access: 2015-10-20

Though our algorithm returns correct results in front of standard traffic lights, the algorithm is not yet able to adjust the estimated waiting time to adaptive traffic lights (traffic lights which use metal detectors and motion sensors in order to detect approaching cars). Further, we do not yet consider different times of the day.

7.6 Implementation

Our prototype system is based on a client-server infrastructure. We implemented two clients for the use on laptops and on mobile phones. Both clients are written in Python. The following chapter provides an overview of requirements and the system architecture.

7.6.1 Requirements

The following requirements have to be satisfied:

Determine vehicle status The system logic needs to be able to distinguish whether a car is moving or not. Due to shortcomings with the GPS-based velocity information, state transitions are used to determine the vehicle status.

TLZ management Standing points need to be associated with TLZs by retrieving existing ones from a central database or new TLZs have to be created and inserted. For existing TLZs the system needs to be capable of recognizing that a vehicle stopped in the same TLZ several times and adapt the estimated waiting time. After each stop, the waiting time needs to be updated in the database.

Content management Based on the estimated waiting time content of appropriate length has to be selected. Content is to be stored either locally or retrieved from the Internet. In order to increase the user experience, users should be able to specify their interests or explicitly select types of content to be shown.

Offline Mode The system needs to be functional without Internet connection as in tunnels or in rural areas coverage may be bad. A local database is used to synchronize regularly with a central database.

Feedback The system should inform other users standing in the same traffic light zone about a change of status (e.g., that the traffic light is expected to change back to green again). Additionally, the user must be able to abort playback and information on these actions need to be stored and handled accordingly.

7.6.2 Hardware

For our prototype we used a Bluemax Bluetooth GPS-4043 recorder as a GPS receiver and logger. The accuracy is specified with 3 m, the maximum frequency is below 1 Hz. As a mobile client we used a Nokia 5800 XpressMusic phone with a pre-installed Python for S60 runtime environment as well as a Python Script Shell 1.4.5.

7.6.3 System Architecture

On our server we used a MySQL server to store TLZs and timing information. The client-server communication is based on PHP. Local (client-side) database information is stored in XML files. TLZs are represented by longitude and latitude, sum of stops, average standing time, longitude and latitude of the direction, maximum and minimum standing time, and standard deviation. We use an application server to enable access between clients and database. Both clients provide similar functionality. They read the current location and velocity from a GPS receiver connected via Bluetooth. In case the velocity drops below the threshold, required data is accessed from the local or remote database. The clients support two modes:

Online Mode Once the vehicle stops the current location and direction is transferred to the database. Based on the retrieved estimated waiting time suitable content is selected for durations of more than 10 seconds. The application server provides a *getStatus()* method for each traffic light. It returns its current status and is used to stop the playback. This also happens if the vehicle starts moving. Finally, the waiting time is written to the database.

Offline Mode Upon the state transition to “vehicle is standing”, the local XML database is checked for the existence of a TLZ at the given location and direction and the decision is made whether content is played back or not. When the zone is left, either the average duration spent in the current zone is recorded or a new zone is being initiated. The currently played back content is stopped.

7.6.4 Media Content

Once our application recognizes that a vehicle came to a halt, we check in the database if a TLZ exists in the current location. In case the expected standing time exceeds 10 seconds (we consider this to be the minimum time to display meaningful content), we select content of appropriate length from a local set. A more sophisticated version could preload content based on the taken route (this information could be extracted from a navigation system) and preload the content, hence making it possible to download up-to-date content on the fly while driving.

7.7 Qualitative Evaluation

To evaluate the system, we conducted several test drives. As content, we used audio clips in combination with still images to ensure a minimal distraction of the driver. The length of the clips varied between 8 and 32 seconds (fitting $X-(s/2)$, where $X \geq 10\,\mathrm{s}$). Depending on the estimated standing time a clip was chosen and played back. Clips were previously stored on the mobile device.

7.7.1 Testing Previously Tagged Routes

For the first evaluation, we had our test person drive a route where we previously created TLZs based on a GPS log. During the drive, we logged the standing times in front of red traffic lights and whether a clip was played back, and compared the duration with the actual standing time. Figure 7.7 depicts a part of the evaluation route. All markers represent positions with state transitions to “vehicle is standing”. Table 7.1 provides a comparison between the estimated waiting time (values from database), the actual standing time (obtained by using a stop watch), and the length of the played clip. In order to test which TLZ a standing point was assigned to, the TLZs were checked and associated based on timestamps.

Results

For each standing point a TLZ was created, the standing point associated with the TLZ and a media clip played back if applicable. Whereas zones 1-12 are actually traffic lights, zone 13 is a left-turn lane. The clip was played back twice due to the stop-and-go behavior of the vehicle. For the zones 4, 9, 10, and 13 the media clip was longer than the actual standing time. The standing time in zones 4, 9, and 13

Figure 7.7: Evaluation route to test the concept of time-adjusted media with pre-recorded TLZs. The markers depict locations where the system detected the car as standing. Blue color is used to show the outward trip and green color for the return trip. Map data: Google, Tele Atlas.

was below 4 seconds. To solve this issue a delay could be added at the beginning of the clip, hence making the playback shorter but more reliable. In zone 3 and 11 the clip was more than 10 seconds shorter than the actual standing time. For zone 11, the standing time exceeded the maximum clip length, for zone 3 the average standing time was below the actual standing time. In total, a majority of the TLZs were detected correctly and playback times matched the standing times quite well.

7.7.2 Testing Previously Untagged Routes

We had the same person make an evaluation drive on a route with no previously stored information on TLZs (see Figure 7.8). The route was driven four times. For the first 3 drives we used the offline mode with an empty XML database, for the last drive we synchronized the XML database with our central database. The fourth drive was conducted in online mode in order to test whether TLZ are built correctly and if synchronization works. During the drive we logged information on position of standing points, the standing duration, and clips that potentially were played back. Markers are again positions where the vehicle stopped. Blue and green colors indicate the driving direction. Table 7.2 gives an overview of the

Table 7.1: Comparison of estimated and actual standing times during a ride with previously tagged TLZs.

TLZ #	Estimated TTI	Actual TTI	Length of selected media clip
1	26.8 s	32 s	27 s
2	10.9 s	15 s	12 s
3	17.8 s	28 s	17 s
4	8.6 s	3 s	8 s
5	9.1 s	12 s	8 s
6	14.1 s	20 s	12 s
7	25 s	34 s	27 s
8	20.7 s	18 s	23 s
9	9.0 s	2 s	8 s
10	32.7 s	24 s	32 s
11	39.2 s	48 s	32 s
12	27.5 s	30 s	27 s
13	9.9 s	3 s	8 s
14	9.9 s	2 s	8 s

actual and the average standing time. All bold entries in that table mark situations that resulted in the creation of a new TLZ. Out of the TLZs, 8 were correctly created in front of traffic lights. Zone 7 was created due to a traffic jam and zones 10 and 11 while waiting behind a tram.

Results

The creation of TLZs worked correctly in most of the cases, the synchronization as well as online and offline mode worked smoothly. As expected the initial building of zones at standing points caused problems since TLZs were also created in locations without traffic lights.

7.7.3 User Feedback

Qualitative user feedback revealed that there might in fact be an effect on users' driving behavior. Our test driver (male, 28 years) stated that he deliberately reduced his use of the engine break and that avoided approaching a traffic light slowly. Instead he tried to halt only in front of the traffic light. We believe that this is because the test driver was keen on seeing the next media clip. Whereas these

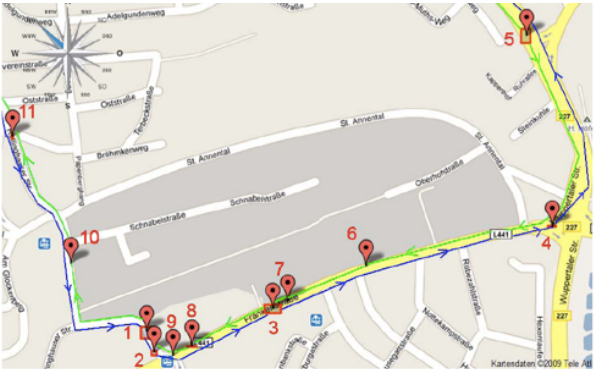


Figure 7.8: Evaluation route to test the concept of time-adjusted media without pre-recorded TLZs. The markers depict locations where the system detected the car as standing. Blue color is used to show the outward trip and green color for the return trip. Map data: Google, Tele Atlas.

findings are certainly not representative they give an idea how the users' behavior might be affected.

7.8 Discussion and Limitations

The current implementation is a proof-of-concept and has therefore several shortcomings, which should be addressed in future versions. For the discussion, we first address the specific approach of our prototype that we described in this chapter. After that, we discuss the extended use case of time-adjusted NDRAs beyond waiting times at traffic lights.

For the specific use case in this chapter, we discussed several challenges, e.g., the distinction between different phenomena in daily traffic that cause vehicles to stop, such as traffic jams, railroad crossings, or parking lots. But still, our algorithm produces decent results.

In the current prototype, there is no way yet to verify if the system estimates the waiting time correctly. With future vehicles and infrastructure objects (traffic lights) that support car-to-X communication, details about the traffic phase could be received from the vehicle in front or the traffic light itself. This could simplify the approach since waiting times do not need to be calculated manually. Even if

Table 7.2: Comparison of estimated and actual standing times for TLZs on a previously untagged route. Times in bold depict situations where a new TLZ was created.

TLZ #	Run 1	Run 2	Run 3	Run 4	Mean standing time
1	-	-	-	**5 s**/33 s	19 s
2	**28 s**	14 s	19 s	21 s	20,5 s
3	**20 s**	6 s	11 s	-	12,3 s
4	**59 s**	47 s	57 s	49 s	53 s
5	**14 s**	10 s	14 s	18 s	14 s
6	-	**12 s**	-	-	12 s
7	-	-	**11 s**	-	11 s
8	-	**11 s**	11 s	-	11 s
9	-	-	-	**9 s**	9 s
10	-	-	**18 s**	- 18 s	
11	-	**11 s**	14 s	-	12,5 s

the waiting times are not directly available, the information that the lead vehicle started moving again could be used to make the systems aware that the traffic light must have turned green again and that the NDRA has to be terminated. Another option could be to use a camera for detecting traffic lights. Since such cameras are already integrated into certain vehicle in order to detect traffic signs (Glavtchev et al. 2011), this would be an additional use case for the camera. As another alternative, additional sensors of ADASs could be used to detect the lead vehicle motion, e.g., using radar or ultrasound.

Another drawback of the current implementation is that the information that a clip has been aborted manually is not assessed at the moment. Such an information could be useful to further classify the current zone, e.g., whether it is a traffic light, yield sign, or railroad crossing. At certain intersections, it is very common that vehicles still cannot cross the intersection during the next green phase. This can be exploited for the presentation of the next content element or NDRA even without information from a database: Once the car has stopped for the second time, it can be assumed that the duration of the next standing interval is at least as long as the previous one if it occurs within the same TLZ. For the technical implementation, we expect further enhancement of our system's accuracy through the advent of new technologies, such as Galileo to detect the current location. Also, obtaining CAN bus information directly from the vehicle (e.g., current velocity) could increase the data quality.

For the overall concept of time-adjusted NDRAs, we see the presented prototype as a first proof-of-concept. We see a high potential to also apply the concept to other situations, especially for those where driving is partly or highly automated. However, we acknowledge that separate investigations are necessary, particularly for those situations where the vehicle is moving,

7.9 Conclusion and Outlook

In this chapter we presented a context-based approach to support time-adjusted media consumption as one example of time-adjusted NDRAs. Especially, we introduced an algorithm that learns standing points and estimates waiting times in typical situations (e.g., traffic lights) in order to tailor (visual) entertainment content that is shown on IVIS displays while almost no attention of the driver to the driving scene is required.

We consider this work to be a first step towards safer car entertainment and other NDRAs. Providing a system that allows tailoring the length of entertainment content or another NDRA to the estimated time where the driver does not need to pay attention to driving has several benefits: We do not only enable a more pleasant driver experience but also allow for making drivers aware of the moment when to direct attention back towards the road. While initially explored for situations where the car is not moving, we expect this approach to be especially useful for highly automated driving. For instance, if the driver enters a highway where highly automated driving is possible, we can imagine the following situation: Since route and destination of the trip are known, the vehicle can calculate how long it will take until the exit where the highway will be left. Based on this time, appropriate NDRA including entertainment as explored in this chapter are offered to the driver. Similar to the waiting situation, the advantage of this approach is that the end of the NDRA, which then coincides with the time to switch to assisted or manual driving, an attention shift of the driver will be necessary anyway. Thus, it may be perceived as more intuitive to become aware of the driving situation at this moment. Also, the driver is expected to be less frustrated since the task does not need to be interrupted at the end of the automated driving phase since it has just been completed. Evaluating the concept in such a situation is of special interest for future use cases.

Evaluating IVISs in the real world is a difficult challenge, since safety might be compromised in case of a malfunction of the system. We conducted a small-scale, qualitative evaluation with non-distractive content (audio and still images), which indicated that there might indeed be a quite significant influence on how drivers approach traffic lights. However, evaluating the effect should be subject of a future large-scale user study. With this regard, it will be of interest to investigate the level of distraction as well as the effect of extended use, that could be extracted from a longer-term field study were people use an entertainment system over the course of several weeks. Initial findings indicate that–especially for daily commuters–such a system might be of value and that it has the potential to increase road safety.

Our proposed concept mainly looked at providing entertainment and NDRAs for the driver. However, we see an increasing demand to also investigate additional interaction possibilities and user interfaces for passengers. These could be separate systems and interfaces, that are not necessarily connected. However, for situations where the driver's attention can be diverted from the road, an alternative could be to provide means to perform and enjoy shared NDRAs for driver and passengers. Likewise, we also see use cases where time-adjusted media can be of interest for passengers. Here, the time to adjust to would be the arrival at intermediate stops or the destination of the trip. Similar to the benefits for the driver, time-adjusted tasks and activities for passengers would spare the need to interrupt an activity at the rest area or destination. A specific use case that employs this approach could be the entertainment of children sitting at the back seat. If the entertaining content ends just when the car arrives at the destination or rest area, there should be no more need to discuss whether the end of the movie needs to be seen before leaving the car.

V

Conclusion and Future Work

Chapter 8

Conclusion and Future Work

In this thesis, we explored the domain of automotive user interfaces and how they can be extended or improved in order to safely support the increasing demand for non-driving-related activities. This chapter provides a summary of the research contributions. Furthermore, we point out future research opportunities in this domain and provide concluding remarks.

8.1 Summary of Research Contributions

Even though the tradition of cars is now longer than 100 years, many considerations about driving safety have only emerged gradually during the last decades. Similarly, the integration of in-vehicle infotainment systems as well as the design of interaction with these devices happened mostly in the past 40 years. Also, the widespread distribution of mobile devices, like smart phones and tablets, began at the end of the 1990s and gained importance during the last decade. All these developments lead to a higher demand for the support of NDRA in the car. We expect this to increase further with the appearance of highly and fully automated vehicles (Cacilo et al. 2015). Prior work often considered separate aspects of the interaction between driver and vehicle and often focused mainly on the most important aspect of driving safety. With this thesis we build on this work but also highlight the importance of a driver-centered development of automotive user interfaces, especially supporting also non-driving-related activities (NDRAs).

For future cars we believe that the range of non-driving-related activities will be a major selling point–especially with the rise of automated cars. Since we assume a gradual support of automated driving modes, user interfaces for future vehicles need to support both manual driving and (highly) automated driving. In the following sections, we summarize the contributions of the developed and evaluated approaches.

8.1.1 Guidelines for the Support of NDRA

The guidelines and model presented in Chapter 3 aid the design and development of automotive interfaces that support a safe execution of non-driving-related activities in the car. Building upon prior work, i.e., existing guidelines, standards, and legal aspects, the goal of the presented framework is to foster the design of attractive and usable interfaces. Even though it is mostly prohibited to use mobile devices while the car is moving, many drivers do so every day. Thus, a special focus of the presented framework is to support activities such as those that are frequently performed on mobile devices today. The motivation for this is that applications on mobile devices often do not fulfill or consider the specific requirements of the driving situation. Carefully embedding such applications in the car instead would allow to adapt them to the driving domain and context.

The context-enabled model should furthermore support the design process. By providing an exemplary information flow along with a set of different context categories and items, we offer a toolkit to developers. The idea is to use it as a starting point for future systems. We envision the description of the entire model to support the designers' and developers' creativity and allow for an easy exploration and analysis of the different aspects. Also, new approaches and situations may be identified using the guidelines and model. For example, designers could use this model to explore the use of different context and input options or adapt the system response according to the current context.

8.1.2 Driver Workload Data Set

With our real-world driving study(Chapter 4), we recorded and published a data set that contains information about physiological driver measurements (skin temperature, skin conductance level, and heart rate), driving context (location, brightness, and acceleration), as well as subjective (post-hoc) workload ratings. This data set can help researches and practitioners during the design and development of future systems since these systems may use the recorded data set for designing and testing purposes.

8.1.3 Multimodal Interaction

In Chapter 5 we presented an approach for multimodal input in the car. By combining speech we can overcome the necessity for time-consuming hierarchical navigation as it is used currently in most IVISs. By using gestures on the steering wheel, speech does not need to be used for the whole interaction, but especially the adjustment can easily be done through touch gestures. As the user-elicited approach showed, simple directional gestures are commonly recognized for adjustment tasks and enable a simple implementation and interaction. The approach can easily be extend to integrate additional modalities such as gaze interaction or mid-air gestures. Mid-air gestures could for instance be integrated as an alternative to touch gestures (e.g., above the center stack, next to the steering wheel) and gaze interaction could support the disambiguation process.

8.1.4 Communication as a NDRA

This thesis contributes to the design of communication tools that are used while driving. These contributions are helpful for car manufactures, mobile network providers, and also phone manufacturers or app developers. Communication with the outside world is a frequent activity that drivers already performed in the car even though the risk of being distracted is known. In Chapter 6 we investigated two interconnected aspects of communication that are relevant while the driver is still in charge of driving. Both are related to sharing information with the outside world. The idea is to share such information in order to make the communication partners aware of the driving situation and, thus, potentially adapt their communication behavior to support an increase of driving safety. First, we investigated which information about a ride drivers are willing to share with the outside world. Second, we examined the specific aspect of sharing a live video stream to the communication partner while driving.

For overall context sharing, we currently see a diverse image of user preferences. In particular, from a remote user's perspective, such information was rated as very valuable. Based on these preferences, we extracted recommendations on when to share context information, which information to share, and how sharing may be different for various target groups. Finally, we identified that video sharing is not yet a convincing feature for most drivers. However, with this regard, we expect an increasing acceptance and a rising demand once such systems become available. For video sharing, we also identified important aspects for the design of systems that share a video link.

8.1.5 Time-Adjusted Entertainment and Productivity

Already today, we see situations where the driver's attention does not need to be fully on the road. This is currently limited to times where the vehicle is not moving (e.g., at traffic lights) but will be soon extended to phases where the vehicle is driving in a fully automated manner for a certain time. Often, the time is known when the driver's attention is needed again, i.e., either when the traffic light turns green again or when the driver needs to take over after a fully automated ride segment. If the driver performs NDRAs when no attention is required, one challenge is to direct the attention back to the road just at the right time. We support this process by providing a concept for time-adjusted NDRAs (Chapter 7). If the remaining time to intervention (TTI) without road attention is known, the IVIS offers tailored tasks to the driver that have an expected end shortly before the time with no attention is over. Thus, the end of the task facilitates the attention shift back to the driving scene.

8.2 Future Work

With this thesis, we provide a starting point for future research on non-driving-related activities and their support through appropriate user interfaces in the car. Reflecting and discussing the presented projects, we identified various open challenges. In the remaining sections of this chapter, we point out these areas of future work.

8.2.1 Communicating While Driving

The presented concept of sharing driving context information with the outside world is one attempt to reduce some demand for communication, create awareness about the current driving context, and ultimately to increase driving safety. Investigating the drivers' and communication partners' preferences is only a first step. As a next step, it would be helpful to plan a large-scale deployment of a specifically crafted app that implements the recommended sharing features. This will potentially involve two separate components. On the one hand, a service on the driver's phone needs to detect the driving situation along with all context details and for instance forward this situation to a central directory. On the other hand, the remote caller's system needs communication applications, such as the phone book or the calling app, that will then connect to the same central component and display the information accordingly.

In the form of a (mobile) "research in the large" approach (Henze and Pielot 2013; Henze, Pielot, et al. 2011), an integration of additional means to analyze communication behavior would allow for a detailed analysis of how the delivery and presentation of context information changes the behavior when communicating with a driver on the road. As one example, different presentation formats (e.g., icons shown in the contacts list or a spoken information while the call is initiated) could be compared in such an experiment with regard to their effect on number of phone calls made or deferred, or the length of phone calls.

The chances for mobile video communication (in the car) were limited with regard to network coverage and especially network speed until recently. With the introduction of high-speed mobile networks, for instance base on LTE technology, it is now possible to also stream videos using a higher bandwidth in many parts of the world. Thus, another experiment could be performed to investigate the effect of road video sharing on the driver's and remote caller's communication behavior as well as the acceptance of such approaches when used "in the wild".

8.2.2 Interfaces for (Automated) Driving

The emergence of automated driving will change many aspects with regard to interaction opportunities in the car. For (novel) NDRAs, this technology will certainly be the most important enabling factor. However, unless the car is driving fully automated for the complete trip, the potential switch to lower levels of driving automation will restrict opportunities. In line with other organizations and researchers (e.g., Kun, Boll, and Schmidt 2016; Politis, Brewster, and Pollick

2015; Trimble et al. 2014) we expect to see a gradual transition towards fully automated driving, that is not expected to be available in production vehicles before 2025 (Trimble et al. 2014). At least until then it is important to also consider the intermediate steps.

In oder to support partial and highly automated driving, we see several research challenges on the user interface side:

- **Mode awareness** As the level of automation can change during a ride, it is important that the driver knows the current level of automation at any time while in the car. The UI therefore needs to provide appropriate hints. So far, first approaches exist, but these need to be investigated in-depth, especially with regard to their compatibility to common NDRAs.

- **Driver state** With an increasing level of driving automation, monitoring the driver becomes important in order to be able to evaluate the driver's capability to take over control again. As outlined before, various approaches to monitor the driver may be used, including physiological sensing. While first approaches to rigorously monitor the driver state have been presented or are currently subject of various research projects, effort needs to be made to allow a robust but unobtrusive and privacy-conserving monitoring in any driving situation. Novel examples that could be applied to the automotive domain include the estimation of workload by measuring the task-evoked pupillary response through eye-tracking (e.g., Pfleging, Fekety, et al. 2016).

- **Changing levels of automation and cooperative driving** When the level of automation changes during a ride, this change needs to be ideally supported by the in-vehicle UI. If a take-over request towards a lower level of automation happens, this needs to be clearly and timely presented to the driver. However, to keep the level of frustration low, a running NDRA should not just be interrupted since this might frustrate the driver. Also, the resumption of such activities might be complicated and time-consuming.

Kun, Boll, and Schmidt (2016) identified different aspects as the new research agenda for automotive user interfaces. The previously mentioned research challenges relate to the safety aspect discussed by these authors. They also discuss NDRAs as another challenge of "Transforming Vehicles into Places of Productivity and Play". We will address this aspect in the following subsection.

8.2.3 Support of Non-Driving-Related Activities

In order to support the driver, it needs to be investigated, which activities may be allowed–for instance when offered through the IVIS–even during lower levels of automation (Cacilo et al. 2015). The set of provided NDRAs will be important for the acceptance of automated driving. Only with a large set of enjoyable activities, we expect automated driving to be of interest to the majority of drivers. In order to support an extensive set of NDRAs, the following research questions need to be answered:

- **Which NDRAs do the drivers want to perform in the car?** As one of the first steps, potential NDRAs need to be identified. In addition to tasks that we already find in vehicles today, it is of particular interest to find out which activities drivers want to perform in highly and fully automated cars. Besides large-scale (web) surveys, such information could be retrieved from observational studies in related domains. For instance, it is of interest to identify the frequencies of the various activities while people use other means of transportation as a passenger such as public transportation, long distance trains, taxis etc. However, due to the characteristics of each mode of transportation, usage patterns may vary. For instance, privacy concerns might inhibit certain activities when other passengers are around in a subway train.
- **Which NDRAs are compatible with the different driving situations?** Once a set of potential non-driving-related activities (NDRAs) has been identified, their compatibility to the driving situation needs to be evaluated. For highly and fully automated driving, this is for instance related to the influence of the activity on the time to take over vehicle control. This might influence whether an activity can be offered and how it can performed by the driver. This could for example affect the choice of input and output technology. Also, the implementation of an application may affect the driving experience and the driver's reaction. For instance, we assume that self-driving carsickness (Diels and Bos 2016) could be an issue which negatively affects the driving experience. We expect that the design of activities and applications-–including the question of where to place input and output devices—may play a very important role to prevent such negative influences.
- **How can we seamlessly integrate an NDRA for manual, assisted, and partly automated driving?** In addition to the activity itself, it needs to be taken into account that the IVIS offers an acceptable transition to a lower level of automation in case of take-over requests. For each activity, suitable

methods need to be found that either provide acceptable alternatives to continue an activity during manual or assisted driving. If this is not possible, suitable means need to be found how to continue an NDRA if the required level of automation is available again.

- **Which novel technologies should be introduced in the car to support NDRAs?** Today we see a variety of novel technologies that arrive on the market but are so far used mainly outside of the vehicle. This includes for instance head-up displays, see-through glasses, or smart watches but also smartphones and tablets. Head-up displays are nowadays offered for selected high-end vehicles. For many of these technologies, it is of interest to analyze the potential of how these technologies can support NDRAs in the car. For instance, small-size head-up displays might be replaced by full-screen windshield displays (Haeuslschmid, Pfleging, and Alt 2016) and enable or support novel applications and activities. Similarly, in-vehicle displays may be extended to 3D displays to improve visualization and understanding (Broy 2016; Broy, Alt, et al. 2014; Broy, Guo, et al. 2015). As most drivers are used to their mobile devices (smartphone and tablet), one particular challenge is the integration and interplay between these devices and the automotive user interface.

8.3 Concluding Remarks

With a history of more than 100 years, driving a vehicle is a well-known activity. The number of non-driving-related activities, however, has mainly been growing notably during the last years. This applies especially to demands for connectivity and extensive infotainment. Only in combination with partly, highly, and fully automated driving, we will get to a situation where the driver has enough freedom to perform arbitrary NDRAs while the car is moving. Until then, existing guidelines, rules, and laws still frame the challenges of enabling such activities during a manual ride where driver distraction cannot be neglected.

During the last year, we saw a notable transition towards offering more activities during a ride. With car-specific apps as offered through Android Auto[1] for Android devices and CarPlay[2] for iOS devices, developers now have the chance to create applications that do not only run on mobile devices but can also use input and output technology in cars. We see this as a starting point for the integration of

[1] https://www.android.com/auto/, last access: 2015-10-20

[2] www.apple.com/ios/carplay/, last access: 2015-10-20

apps, i.e., NDRAs, into the car that the driver is using on a mobile device anyway. However, such an integration is challenging and it is important for the mobile developers and also for car manufacturers to carefully design and investigate the interface shown in the car (Gable, Walker, and Amontree 2015).

Especially in combination with cars that enable highly or fully automated driving, we expect fundamental changes to happen regarding the function of a car. The selection of activities that can be offered during a ride will be a novel and important selling point for future vehicles. This thesis provides fundamental insights in how to support non-driving-related activities during a ride. Given the current pace of technology and human-computer interaction, it is obvious that the contributions are temporary solutions but might shape the future of in-vehicle interaction. Currently, vehicles become an important area for computing technology, especially with respect to entertainment, human-computer interaction, and automation. It is up to the researchers, developers, and designers of cars to carefully explore these novel opportunities and to ensure safe driving while providing the best driving experience.

VI

Bibliography

Bibliography

AAM Driver Focus-Telematics Working Group (2006). *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In- Vehicle Information and Communication Systems*. Tech. rep. Alliance of Automobile Manufacturers.

Motoyuki Akamatsu, Paul Green, and Klaus Bengler (2013). Automotive Technology and Human Factors Research: Past, Present, and Future. In: *International Journal of Vehicular Technology* 2013, 526180. 27 pages. DOI: 10.1155/2013/526180.

Suat Akyol, Ulrich Canzler, Klaus Bengler, and Wolfgang Hahn (2000). Gesture Control for Use in Automobiles. In: *Proceedings of the IAPR Workshop on Machine Vision Applications 2000*. (MVA2000. Tokyo, Japan). Nov. 2000, pp. 349–352.

Florian Alt, Dagmar Kern, Fabian Schulte, Bastian Pfleging, Alireza Sahami Shirazi, and Albrecht Schmidt (2010). Enabling Micro-Entertainment in Vehicles Based on Context Informationm. In: *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '10. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 117–124. ISBN: 978-1-4503-0437-5. DOI: 10.1145/1969773.1969794.

Florian Alt, Alireza Sahami Shirazi, Max Pfeiffer, Paul Holleis, and Albrecht Schmidt (2009). TaxiMedia: An Interactive Context-Aware Entertainment and Advertising System. In: *Proceedings of the Second International Workshop on Pervasive Advertising*. (PerAd'09. Lübeck, Germany). Lübeck, Germany, Oct. 2009.

Ignacio Alvarez, Hanan Alnizami, Jerone Dunbar, Andrea Johnson, France Jackson, and Juan E. Gilber (2011). Designing Driver-Centric Natural Voice User Interfaces. In: *Adjunct Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria), pp. 156–159. URL: http://auto-ui.org/11/docs/AUI2011_adjunctproceedings.pdf#page=156.

M. Anderson (1903). Window-Cleaning Device. US743801. US Patent 743,801. Nov. 1903.

Leonardo Angelini, Maurizio Caon, Francesco Carrino, Stefano Carrino, Denis Lalanne, OmarAbou Khaled, and Elena Mugellini (2013). WheelSense: Enabling Tangible Gestures on the Steering Wheel for In-Car Natural Interaction. English. In: *Human-Computer Interaction. Applications and Services*. Ed. by Masaaki Kurosu. Vol. 8005. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 531–540. ISBN: 978-3-642-39261-0. DOI: 10.1007/978-3-642-39262-7_60.

Jon Antin, Suzie Lee, Jon Hankey, and Tom Dingus (2011). *Design of the In-Vehicle Driving Behavior and Crash Risk Study*. SHRP 2 Report S2-S05-RR-1. The National Academies Press. ISBN: 978-0-309-12895-7. DOI: 10.17226/14494.

Bernhard Anzengruber and Andreas Riener (2012). "FaceLight": Potentials and Drawbacks of Thermal Imaging to Infer Driver Stress. In: *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '12. Portsmouth, New Hampshire). ACM: New York, NY, USA, pp. 209–216. ISBN: 978-1-4503-1751-1. DOI: 10.1145/2390256.2390292.

ARIS Umfrageforschung Markt-, Media- und Sozialforschungsgesellschaft mbH (2011). *Studie Automobil. ITK im Auto und Elektromobilität*. Slides. URL: https://www.bitkom.org/noindex/Publikationen/2011/Studie/Studie-Automobil-ITK-im-Auto-und-Elektromobilitaet/BITKOM-Studie-Automobil-ITK-im-Auto-und-Elektromobilitaet.pdf.

ARIS Umfrageforschung Markt-, Media- und Sozialforschungsgesellschaft mbH (2013). *Intelligente Mobilität – Smarte Lösungen für Autofahrer*. Slides. Sept. 2013. URL: http://www.bitkom.org/de/themen/39647_77378.aspx.

Jóhannes Ingi Árnason, Jannik Jepsen, Allan Koudal, Michael Rosendahl Schmidt, and Stefania Serafin (2014). Volvo Intelligent News: A Context Aware Multi Modal Proactive Recommender System for In-Vehicle Use. In: *Pervasive and Mobile Computing* 14 (Oct. 2014). Special Issue on Pervasive Education Special Issue on The Social Car: Socially-inspired Mechanisms for Future Mobility Services, pp. 95–111. ISSN: 1574-1192. DOI: 10.1016/j.pmcj.2014.06.005.

Fabrice Axisa, Pierre Michael Schmitt, Claudine Gehin, Georges Delhomme, Eric McAdams, and André Dittmar (2005). Flexible Technologies and Smart Clothing for Citizen Medicine, Home Healthcare, and Disease Prevention. In: *IEEE Transactions on Information Technology in Biomedicine* 9.3 (Sept. 2005), pp. 325–336. ISSN: 1089-7771. DOI: 10.1109/TITB.2005.854505.

Kenneth Majlund Bach, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen (2008). You Can Touch, but You Can't Look: Interacting with In-Vehicle Systems. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '08. Florence, Italy). ACM: New York, NY, USA, pp. 1139–1148. ISBN: 978-1-60558-011-1. DOI: 10.1145/1357054.1357233.

Kenneth Majlund Bach, Mads Gregers Jæger, Mikael B. Skov, and Nils Gram Thomassen (2009). Interacting with In-vehicle Systems: Understanding, Measuring, and Evaluating Attention. In: *Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology*. (BCS-HCI '09. Cambridge, United Kingdom). British Computer Society: Swinton, UK, pp. 453–462.

Roland Bader, Oliver Siegmund, and Wolfgang Woerndl (2011). A Study on User Acceptance of Proactive In-vehicle Recommender Systems. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 47–54. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381424.

Aaron Bangor, Philip T. Kortum, and James T. Miller (2008). An Empirical Evaluation of the System Usability Scale. In: *International Journal of Human-Computer Interaction* 24.6, pp. 574–594. DOI: 10.1080/10447310802205776.

Adriana Barón and Paul A. Green (2006). *Safety and Usability of Speech Interfaces for In-Vehicle Tasks while Driving: A Brief Literature Review*. Internal report UMTRI-2006-5. Ann Arbor, MI, USA: The University of Michigan Transportation Research Institute (UMTRI), Feb. 2006. URL: http://www.umich.edu/~driving/publications/UMTRI-2006-5a.pdf.

Gerd Baumann, Philip Rumbolz, Anne Piegsa, Michael Grimm, and Hans-Christian Reuss (2010). Analyse des Fahrereinflusses auf den Energieverbrauch von konventionellen und Hybridfahrzeugen mittels Fahrversuch und interaktiver Simulation. In: *VDI-Berichte 2107*. (15. Kongress Berechnung und Simulation im Fahrzeugbau 2010. Baden-Baden, Germany), pp. 69–84.

Jackson Beatty (1983). Task-Evoked Pupillary Responses, Processing Load, and the Structure of Processing Resources. In: *Psychological Bulletin* 91.2 (Mar. 1983), pp. 276–292. DOI: 10.1037/0033-2909.91.2.276.

Benz And Co. (1886). Fahrzeug mit Gasmotorenbetrieb. German. DE 37 435 A. Nov. 1886. URL: http://www.dpma.de/docs/service/klassifikationen/ipc/auto_ipc/de37435a.pdf.

Michael Bischof, Ludger Ey, Alexander Kuck, Michael Rahier, and Thomas Ritz (2015). Nutzerzentrierte Gestaltung und Entwicklung eines kontextsensitiven HMI. In: *Mensch und Computer 2015 – Workshopband*. (Mensch und Computer 2015. Stuttgart, Germany). Ed. by Anette Weisbecker, Michael Burmester, and Albrecht Schmidt. De Gruyter Oldenbourg: Berlin, Sept. 2015, pp. 467–474. ISBN: 9783110443905. DOI: 10.1515/9783110443905-067.

Richard A. Bolt (1980). "Put-that-there": Voice and Gesture at the Graphics Interface. In: *SIGGRAPH Comput. Graph.* 14.3 (July 1980), pp. 262–270. ISSN: 0097-8930. DOI: 10.1145/965105.807503.

Azzedine Boukerche, Horacio A. B. F. Oliveira, Eduardo F. Nakamura, and Antonio A. F. Loureiro (2008). Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems. In: *Computer Communications* 31.12. Mobility Protocols for ITS/VANET, pp. 2838–2849. ISSN: 0140-3664. DOI: 10.1016/j.comcom.2007.12.004.

John Brooke (1996). SUS-A Quick and Dirty Usability Scale. In: *Usability evaluation in industry*. Ed. by Patrick W. Jordan, B. Thomas, Ian Lyall McClelland, and Bernard Weerdmeester. Taylor and Francis / CRC Press: London, UK. Chap. 21, pp. 189–194. ISBN: 9780748404605.

John Brooke (2013). SUS: A Retrospective. In: *Journal of Usability Studies* 8.2 (Feb. 2013), pp. 29–40. URL: https://uxpa.org/sites/default/files/JUS_Brooke_February_2013_0.pdf.

Johnell O. Brooks, Richard R. Goodenough, Matthew C. Crisler, Nathan D. Klein, Rebecca L. Alley, Beatrice L. Koon, William C. Logan Jr., Jennifer H. Ogle, Richard A. Tyrrell, and Rebekkah F. Wills (2010). Simulator Sickness During Driving Simulation Studies. In: *Accident Analysis & Prevention* 42.3. Assessing Safety with Driving Simulators, pp. 788–796. ISSN: 0001-4575. DOI: 10.1016/j.aap.2009.04.013.

Nora Broy (2016). Stereoscopic 3D User Interfaces: Exploring the Potentials and Risks of 3D Displays in Cars. PhD thesis. University of Stuttgart. DOI: 10.18419/opus-8851.

Nora Broy, Florian Alt, Stefan Schneegass, and Bastian Pfleging (2014). 3D Displays in Cars: Exploring the User Performance for a Stereoscopic Instrument Cluster. In: *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '14. Seattle, WA, USA). ACM: Seattle, WA, USA, 2:1–2:9. ISBN: 978-1-4503-3212-5. DOI: 10.1145/2667317.2667319.

Nora Broy, Mengbing Guo, Stefan Schneegass, Bastian Pfleging, and Florian Alt (2015). Introducing Novel Technologies in the Car: Conducting a Real-world Study to Test 3D Dashboards. In: *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '15. Nottingham, UK). ACM: New York, NY, USA, pp. 179–186. ISBN: 978-1-4503-3736-6. DOI: 10.1145/2799250.2799280.

Marie-Pierre Bruyas and Laëtitia Dumont (2013). Sensitivity of Detection Response Task (DRT) to the Driving Demand and Task Difficulty. In: *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '13. Bolton Landing, NY, USA), pp. 64–70. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/011_Bruyas_0.pdf.

Heiner Bubb (1993). Systemergonomische Gestaltung. In: *Ergonomie*. Ed. by Heinz Schmidtke. 3. neubearb. und erw. Aufl. Carl Hanser Verlag: Munich and Vienna, pp. 390–420. ISBN: 3-446-16440-5.

Heiner Bubb (2003). Fahrerassistenz - primär ein Beitrag zum Komfort oder fuer die Sicherheit? In: *Der Fahrer im 21. Jahrhundert : Anforderungen, Anwendungen, Aspekte für Mensch-Maschine-Systeme; Tagung Braunschweig, 2.*

und 3. Juni 2003. (VDI-Berichte 1768. Braunschweig, Germany). VDI-Verlag: Düsseldorf, Germany, pp. 25–44. ISBN: 3-18-091768-7.

Gesetz zu den Übereinkommen vom 8. November 1968 über den Straßenverkehr und über Straßenverkehrszeichen, zu den Europäischen Zusatzübereinkommen vom 1. Mai 1971 zu diesen Übereinkommen sowie zum Protokoll vom 1. März 1973 über Straßenmarkierungen (1977). In: *Bundesgesetzblatt Teil II* 39 (Oct. 1977). Ed. by Bundesministerium der Justiz, pp. 809–1111. ISSN: 0341-1109. URL: http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl277s0809.pdf.

Gary E. Burnett (2009). On-the-Move and in Your Car: An Overview of HCI Issues for In-Car Computing. In: *International Journal of Mobile Human Computer Interaction (IJMHCI)* 1.1, pp. 60–78. DOI: 10.4018/jmhci.2009010104.

Andreas Butz and Antonio Krüger (2014). *Mensch-Maschine-Interaktion*. De Gruyter Oldenbourg: Berlin and Boston. ISBN: 978-3-486-71967-3.

James C. Byers, Alvah C. Bittner Jr., and Susan G. Hill (1989). Traditional and Raw Task Load Index (TLX) Correlations: Are Paired Comparisons Necessary? In: *Proceedings of the Annual International Industrial Ergonomics and Safety Conference*. (Advances in Industrial Ergonomics and Safety. Cincinnti, OH, USA). Ed. by Anil Mital. Vol. I. Taylor & Francis: London, New York, Philadelphia, pp. 481–486. ISBN: 0-85066-493-4.

Andrej Cacilo, Sarah Schmidt, Philipp Wittlinger, Florian Herrmann, Wilhelm Bauer, Oliver Sawade, Hannes Doderer, Matthias Hartwig, and Volker Scholz (2015). *Hochautomatisiertes Fahren auf Autobahnen - Industriepolitische Schlussfolgerungen. Dienstleistungsprojekt 15/14 Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi)*. Project Report. Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO, Nov. 2015. URL: http://www.bmwi.de/BMWi/Redaktion/PDF/H/hochautomatisiertes-fahren-auf-autobahnen,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf.

Jeff K. Caird, Chip T. Scialfa, Geoff Ho, and Alison Smiley (2005). A Meta-Analysis of Driving Performance and Crash Risk Associated with the Use of Cellular Telephones While Driving. In: *Proceedings of the 3rd International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '05. Rockport, MA, USA), pp. 478–485. URL: http://drivingassessment.uiowa.edu/DA2005/PDF/70_Cairdformat.pdf.

Jeff K. Caird, Chelsea R. Willness, Piers Steel, and Chip T. Scialfa (2008). A Meta-Analysis of the Effects of Cell Phones on Driver Performance. In: *Accident Analysis & Prevention* 40.4, pp. 1282–1293. ISSN: 0001-4575. DOI: 10.1016/j.aap.2008.01.009.

Car 2 Car Communication Consortium (2007). *CAR 2 CAR Communication Consortium Manifesto*. Technical Report Version 1.1. Car 2 Car Communication Consortium, Aug. 2007. URL: https://www.car-2-car.org/index.php?id=31.

Stuart K. Card, Thomas P. Moran, and Allen Newell (1980). The Keystroke-Level Model for User Performance Time with Interactive Systems. In: *Commun. ACM* 23.7 (July 1980), pp. 396–410. ISSN: 0001-0782. DOI: 10.1145/358886.358895.

E. Chin, F. Nathan, Annie Pauzié, J. Manzano, E. Nodari, C. Cherri, A. Rambaldini, A. Roffetti, and M. Marchitto (2006). *Subjective Assessment Methods for Workload*. Tech. rep. IST-1-507674-IP D2.2.6. Information Society Technologies (IST) Programme - AIDE - Adaptive Integrated Driver-vehicle InterfacE, Jan. 2006. URL: http://www.aide-eu.org/pdf/sp2_deliv_new/aide_d2_2_6.pdf.

Christian Collet, Philippe Averty, Georges Delhomme, André Dittmar, and Evelyne Vernet-Maury (2003). Subjective Aspects of Mental Workload in Air-Traffic Control. In: *Operator Functional State: The Assessment and Prediction of Human Performance Degradation in Complex Tasks*. Ed. by G. Robert J. Hockey, Anthony W. K. Gaillard, and Oleksandr Burov. Vol. 355. I: Life and Behavioural Scienes. IOS Press: Amsterdam, The Netherlands, Sept. 2003, pp. 291–302. ISBN: 978-1-58603-362-0.

Commission of the European Communities (1978). Council Directive 78/316/EEC of 21 December 1977 on the Approximation of the Laws of the Member States Relating to the Interior Fittings of Motor Vehicles (Identification of Controls, Tell-Tales and Indicators). In: *Official Journal of the European Communities* 21.L81 (Mar. 1978), pp. 3–26. ISSN: 0378-6978. URL: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31978L0316.

Commission of the European Communities (2007). Commission Recommendation of 22 December 2006 on Safe and Efficient In-Vehicle Information and Communication Systems: Update of the European Statement of Principles on Human Machine Interface (2007/78/EC). In: *Official Journal of the European Union* 50.L32 (Feb. 2007), pp. 200–241. ISSN: 1725-2555. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2007.032.01.0200.01.ENG.

Antonia S. Conti, Carsten Dlugosch, Felix Schwarz, and Klaus Bengler (2013). Driving and Speaking: Revelations by the Head-Mounted Detection Response Task. In: *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '13. Bolton Landing, NY, USA), pp. 362–368. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/056_Conti_0.pdf.

Joseph F. Coughlin, Bryan Reimer, and Bruce Mehler (2011). Monitoring, Managing, and Motivating Driver Safety and Well-Being. In: *IEEE Pervasive Comput-*

ing 10.3 (July 2011), pp. 14–21. ISSN: 1536-1268. DOI: 10.1109/MPRV.2011.54.

David G. Curry (2001). In-Vehicle Cell Phones: Fatal Distraction—Yes or No? In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 45.5, pp. 562–566. DOI: 10.1177/154193120104500504.

Edward S. De Guzman, Moushumi Sharmin, and Brian P. Bailey (2007). Should I Call Now? Understanding What Context is Considered when Deciding Whether to Initiate Remote Communication via Mobile Devices. In: *Proceedings of Graphics Interface 2007*. (GI '07. Montreal, QC, Canada). ACM: New York, NY, USA, pp. 143–150. ISBN: 978-1-56881-337-0. DOI: 10.1145/1268517.1268542.

Dick de Waard (1996). The Measurement of Drivers' Mental Workload. PhD thesis. Haren, The Netherlands: University of Groningen. ISBN: 90-6807-308-7.

Department of Transportation and National Highway Traffic Safety Administration (2013). Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Device. In: *Federal Register* 78.81, pp. 24817–24890. URL: https://federalregister.gov/a/2013-09883.

Deutsches Institut für Normung (1999). Ergonomische Anforderungen für Bürotätigkeiten mit Bildschirmgeräten. Teil 11: Anforderungen an die Gebrauchstauglichlkeit – Leitsätze (ISO 9241-11:1998) Deutsche Fassung EN ISO 9241-11:1998. DIN EN ISO 9211-11:1999. Beuth Verlag: Berlin, Germany.

Deutsches Institut für Normung (2000). Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung. Teil 2: Gestaltungsgrundsätze (ISO 10075-2:1996) Deutsche Fassung EN ISO 10075-2:2000. DIN EN ISO 10075-2:2000. Beuth Verlag: Berlin, Germany.

Deutsches Institut für Normung (2003a). Straßenfahrzeuge – Ergonomische Aspekte von Fahrerinformations- und assistenzsystemen - Grundsätze und Prüfverfahren des Dialogmanagements (ISO 15005:2002); Deutsche Fassung EN ISO 15005:2002. DIN EN ISO 15005:2003-10. Beuth Verlag: Berlin, Germany, Oct. 2003.

Deutsches Institut für Normung (2003b). Straßenfahrzeuge – Ergonomische Aspekte von Fahrerinformations- und Assistenzsystemen - Verfahren zur Bewertung der Gebrauchstauglichkeit beim Führen eines Kraftfahrzeugs (ISO 17287:2003); Deutsche Fassung EN ISO 17287:2003. DIN EN ISO 17287:2003-10. Beuth Verlag: Berlin, Germany, 2003.

Deutsches Institut für Normung (2004). Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung. Teil 3: Grundsätze und Anforderungen an Verfahren zur Messung und Erfassung psychischer Arbeitsbelastung (ISO 10075-3:2004); Deutsche Fassung EN ISO 10075-3:2004. DIN EN ISO 10075-3:2004. Beuth Verlag: Berlin, Germany.

Deutsches Institut für Normung (2011a). Ergonomie der Mensch-System-Interaktion – Teil 210: Prozess zur Gestaltung gebrauchstauglicher interaktiver Systeme (ISO 9421-2010:2010); Deutsche Fassung EN ISO 9241-210:2010. DIN EN ISO 9211-210:2011. Beuth Verlag: Berlin, Germany, 2011.

Deutsches Institut für Normung (2011b). Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung. Teil 1: Allgemeines und Begriffe (ISO 10075:1991) Deutsche Fassung EN ISO 10075-1:2000. DIN EN ISO 10075-1:2011. Beuth Verlag: Berlin, Germany, 2011.

Deutsches Institut für Normung (2011c). Straßenfahrzeuge – Ergonomische Aspekte von Fahrerinformations- und Assistenzsystemen – Anforderungen und Bewertungsmethoden der visuellen Informationsdarstellung im Fahrzeug (ISO 15008:2009); Deutsche Fassung EN ISO 15008:2009. DIN EN ISO 15008:2011-06. Beuth Verlag: Berlin, Germany, 2011.

Deutsches Institut für Normung (2012). Straßenfahrzeuge – Ergonomische Aspekte von Verkehrsinformations- und Assistenzsystemen – Anforderungen und Konformitätsverfahren für die Ausgabe auditiver Informationen im Fahrzeug (ISO 15006:2011); Deutsche Fassung EN ISO 15006:2011. DIN EN ISO 15006:2012-04. Beuth Verlag: Berlin, Germany.

Deutsches Institut für Normung (2013). Straßenfahrzeuge – Messung zum visuellen Verhalten des Fahrers in Bezug zu Transportinformationen und Regelsystemen – Teil 1: Definitionen und Parameter (ISO/DIS 15007-1:2013); Englische Fassung prEN ISO 15007-1:2013. DIN EN ISO 15007-1:2013. Entwurf. Beuth Verlag: Berlin, Germany.

Deutsches Institut für Normung (2014). Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung – Ergänzende Begriffe und Erläuterungen zu DIN EN ISO 10075-1:2000-11. DIN SPEC 33418:2014-03. Beuth Verlag: Berlin, Germany.

Cyriel Diels and Jelte E. Bos (2016). Self-Driving Carsickness. In: *Applied Ergonomics* 53, Part B, pp. 374–382. ISSN: 0003-6870. DOI: 10.1016/j.apergo.2015.09.009.

T. A. Dingus, S.G. Klauer, V. L. Neale, Petersen A., S. E. Lee, J. Sudweeks, M. A. Perez, J. Hankey, D. Ramsey, S. Gupta, C. Bucher, Z. R. Doerzaph, J. Jermeland, and R.R. Knipling (2006). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment*. Tech. rep. DOT HS 810 593. Washington, DC, USA: National Highway Transportation Safety Administration. URL: http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/100CarMain.pdf.

Tanja Döring, Dagmar Kern, Paul Marshall, Max Pfeiffer, Johannes Schöning, Volker Gruhn, and Albrecht Schmidt (2011). Gestural Interaction on the Steering Wheel: Reducing the Visual Demand. In: *Proceedings of the SIGCHI Con-*

ference on Human Factors in Computing Systems. (CHI '11. Vancouver, BC, Canada). ACM: New York, NY, USA, pp. 483–492. ISBN: 978-1-4503-0228-9. DOI: 10.1145/1978942.1979010.

Ronald Ecker, Verena Broy, Andreas Butz, and Alexander De Luca (2009). pieTouch: A Direct Touch Gesture Interface for Interacting with In-vehicle Information Systems. In: *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*. (MobileHCI '09. Bonn, Germany). ACM: New York, NY, USA, 22:1–22:10. ISBN: 978-1-60558-281-8. DOI: 10.1145/1613858.1613887.

Rob Eenink, Yvonne Barnard, Martin Baumann, Xavier Augros, and Fabian Utesch (2014). UDRIVE: The European Naturalistic Driving Study. In: *Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment*. (Paris, France).

Christoph Endres, Tim Schwartz, and Christian A. Müller (2011). “Geremin”: 2D Microgestures for Drivers Based on Electric Field Sensing. In: *Proceedings of the 16th International Conference on Intelligent User Interfaces*. (IUI '11. Palo Alto, CA, USA). ACM: New York, NY, USA, pp. 327–330. ISBN: 978-1-4503-0419-1. DOI: 10.1145/1943403.1943457.

Mica R. Endsley and Esin O. Kiris (1995). The Out-of-the-Loop Performance Problem and Level of Control in Automation. In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37.2, pp. 381–394. DOI: 10.1518/001872095779064555.

Johan Engström, Nina Åberg, Emma Johansson, and Jakob Hammarback (2005). Comparison between Visual and Tactile Signal Detection Tasks Applied to the Safety Assessment of In-Vehicle Information Systems. In: *Proceedings of the 3rd International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '05. Rockport, MA, USA), pp. 232–239. URL: http://drivingassessment.uiowa.edu/DA2005/PDF/34_Engstr%C3%B6m%C3%85bergformat.pdf.

Johan Engström, Emma Johansson, and Joakim Östlund (2005). Effects of Visual and Cognitive Load in Real and Simulated Motorway Driving. In: *Transportation Research Part F: Traffic Psychology and Behaviour* 8.2. The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems In-vehicle information systems, pp. 97–120. ISSN: 1369-8478. DOI: 10.1016/j.trf.2005.04.012.

European Committee for Standardization (2002). Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems - Dialogue Management Principles and Compliance Procedures (ISO 15005:2002). EN ISO 15005:2002. Brussels, Belgium, July 2002.

Andreas Festag, Roberto Baldessari, Wenhui Zhang, Long Le, Amardeo Sarma, and Mastoshi Fukukawa (2008). CAR-2-X Communication for Safety and Infotainment in Europe. In: *NEC Technical Journal* 3.1 (Mar. 2008), pp. 21–26. URL: http://www.nec.com/en/global/techrep/journal/g08/n01/pdf/080106.pdf.

James P. Foley, Richard Young, Linda Angell, and Joshua E. Domeyer (2013). Towards Operationalizing Driver Distraction. In: *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '13. Bolton Landing, NY, USA), pp. 57–63. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/010_Foley_0.pdf.

Dillon Funkhouser and Susan T. Chrysler (2007). *Assessing Driver Distraction due to In-Vehicle Video Systems through Field Testing at the Pecos Research and Testing Center*. Tech. rep. SWUTC/07/473700-00082-1. College Station, TX, USA: Texas Transportation Institute, Mar. 2007. URL: http://swutc.tamu.edu/publications/technicalreports/473700-00082-1.pdf.

Thomas M. Gable, Bruce N. Walker, and Andrew S. Amontree (2015). Investigating a New Display Format for CarPlay to Decrease Impact of Mode Change Inputs. In: *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '15. Nottingham, United Kingdom). ACM: New York, NY, USA, pp. 171–178. ISBN: 978-1-4503-3736-6. DOI: 10.1145/2799250.2799277.

Tom M. Gasser, Clemens Arzt, Mihiar Ayoubi, Arne Bartels, Jana Eier, Frank Flemisch, Dirk Häcker, Tobias Hesse, Werner Huber, Christine Lotz, Markus Maurer, Simone Ruth-Schumacher, Jürgen Schwarz, and Wolfgang Vogt (2012). *Rechtsfolgen zunehmender Fahrzeugautomatisierung : gemeinsamer Schlussbericht der Projektgruppe*. Berichte der Bundesanstalt für Straßenwesen, Unterreihe "Fahrzeugsicherheit" F 83. Wirtschaftsverl. NW Verl. für neue Wissenschaft: Bremerhaven. ISBN: 978-3-86918-189-9. URL: http://d-nb.info/1019821272/04.

Valerie Jane Gawron (2008). Human Workload. In: *Human Performance, Workload, and Situational Awareness Measures Handbook*. Second edition. CRC Press. Chap. 3, pp. 87–230. ISBN: 978-1-4200-6450-6. DOI: 10.1201/9781420064506.ch3.

Georg Geiser (1985). Man Machine Interaction in Vehicles. In: *ATZ - Automobiltechnische Zeitschrift* 87, pp. 77–81.

Hamid Gharavi, K. Venkatesh Prasad, and Petros Ioannou (2007). Scanning Advanced Automobile Technology. In: *Proceedings of the IEEE* 95.2 (Feb. 2007), pp. 328–333. ISSN: 0018-9219. DOI: 10.1109/JPROC.2006.888380.

Vladimir Glavtchev, Pinar Muyan-Özcelik, Jeffrey M. Ota, and John D. Owens (2011). Feature-based speed limit sign detection using a graphics processing unit. In: *2011 IEEE Intelligent Vehicles Symposium (IV)*. (IV 2011. Baden-Baden, Germany). IEEE, May 2011, pp. 195–200. ISBN: 978-1-4577-0890-9. DOI: 10.1109/IVS.2011.5940539.

Christian Gold, Daniel Damböck, Lutz Lorenz, and Klaus Bengler (2013). "Take over!" How long does it take to get the driver back into the loop? In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 57.1, pp. 1938–1942. DOI: 10.1177/1541931213571433.

Joan Gómez-Clapers and Ramon Casanella (2012). A Fast and Easy-to-Use ECG Acquisition and Heart Rate Monitoring System Using a Wireless Steering Wheel. In: *IEEE Sensors Journal* 12.3 (Mar. 2012), pp. 610–616. ISSN: 1530-437X. DOI: 10.1109/JSEN.2011.2118201.

Iván E. González, Jacob O. Wobbrock, Duen Horng Chau, Andrew Faulring, and Brad A. Myers (2007). Eyes on the Road, Hands on the Wheel: Thumb-based Interaction Techniques for Input on Steering Wheels. In: *Proceedings of Graphics Interface 2007*. (GI '07. Montreal, QC, Canada). ACM: New York, NY, USA, pp. 95–102. ISBN: 978-1-56881-337-0. DOI: 10.1145/1268517.1268535.

Daniel Gopher and Emanuel Donchin (1986). Workload: An Examination of the Concept. Vol. 2: Cognitive processes and performance. In: *Handbook of Perception and Human Performance*. Ed. by Kenneth R. Boff, Lloyd Kaufman, and James P. Thomas. Vol. 2. John Wiley & Sons: Oxford, United Kingdom. Chap. 41, 41:1–41:49.

Areti Goulati and Dalila Szostak (2011). User Experience in Speech Recognition of Navigation Devices: An Assessment. In: *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*. (MobileHCI '11. Stockholm, Sweden). ACM: New York, NY, USA, pp. 517–520. ISBN: 978-1-4503-0541-9. DOI: 10.1145/2037373.2037451.

Paul A. Green (1999a). Estimating Compliance with the 15-Second Rule for Driver-Interface Usability and Safety. In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 43.18 (1999), pp. 987–991. DOI: 10.1177/154193129904301809.

Paul A. Green (1999b). The 15-Second Rule for Driver Information Systems. In: *ITS America Ninth Annual Meeting Conference Proceedings*. (ITS Annual Meting 99). 1999.

Paul A. Green (2008). Driver Interface/HMI Standards to Minimize Driver Distraction/Overload. In: *Convergence 2008 Conference Proceedings*. (Detroit, Michigan). Society of Automotive Engineers. SAE International: Warrendale, PA, USA.

Paul A. Green (2009). Driver Interface Safety and Usability Standards: An Overview. In: *Driver Distraction : Theory, Effects, and Mitigation*. Ed. by Michael A. Regan Kristie Young John D. Lee. CRC Press: Boca Raton, FL, USA. Chap. 25, pp. 445–461. ISBN: 978-0-8493-7426-5. DOI: 10.1201/9781420007497.ch25.

Paul A. Green (2012). Motor Vehicle-Driver Interfaces. In: *Human-Computer Interaction. Fundamentals, Evolving Technologies, and Emerging Applications, Third Edition*. Ed. by Julie A. Jacko. Third Edition. CRC Press: Boca Raton, FL, USA. Chap. 32, pp. 749–770. ISBN: 978-1-4398-2943-1. DOI: 10.1201/b11963-37.

Paul A. Green (2013). Standard Definitions for Driving Measures and Statistics: Overview and Status of Recommended Practice J2944. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 184–191. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516542.

Fot-Net 2 Working Groups (2014). *FESTA Handbook*. Feb. 2014. URL: http://fot-net.eu/wp-content/uploads/sites/7/2014/06/FESTA_HBK_rev5_ref3-2.pdf.

Anton Gustafsson, John Bichard, Liselott Brunnberg, Oskar Juhlin, and Marco Combetto (2006). Believable Environments: Generating Interactive Storytelling in Vast Location-Based Pervasive Games. In: *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology*. (ACE '06. Hollywood, CA, USA). ACM: New York, NY, USA. ISBN: 1-59593-380-8. DOI: 10.1145/1178823.1178852.

Renate Haeuslschmid, Bastian Pfleging, and Florian Alt (2016). A Design Space to Support the Development of Windshield Applications for the Car. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. (CHI '16. San Jose, CA, USA). ACM: New York, NY, USA, pp. 5076–5091. ISBN: 978-1-4503-3362-7. DOI: 10.1145/2858036.2858336.

Wilfried Hajek, Irina Gaponova, Karl-Heinz Fleischer, and Josef Krems (2013). Workload-Adaptive Cruise Control – A new Generation of Advanced Driver Assistance Systems. In: *Transportation Research Part F: Traffic Psychology and Behaviour* 20, pp. 108–120. ISSN: 1369-8478. DOI: 10.1016/j.trf.2013.06.001.

Joanne L. Harbluk, Peter C. Burns, Sebastian Hernandez, Jane Tam, and Viliam Glazduri (2013). Detection Response Tasks: Using Remote, Headmounted and Tactile Signals to Assess Cognitive Demand While Driving. In: *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '13. Bolton Landing, NY, USA), pp. 78–84. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/013_Harbluk_0.pdf.

Joanne L. Harbluk, Y. Ian Noy, Patricia L. Trbovich, and Moshe Eizenman (2007). An On-Road Assessment of Cognitive Distraction: Impacts on Drivers' Visual Behavior and Braking Performance. In: *Accident Analysis & Prevention* 39.2 (Mar. 2007), pp. 372–379. ISSN: 0001-4575. DOI: 10.1016/j.aap.2006.08.013.

Sandra G. Hart (2006). Nasa-Task Load Index (NASA-TLX); 20 Years Later. In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50.9, pp. 904–908. DOI: 10.1177/154193120605000909.

Sandra G. Hart and Lowell E. Stavenland (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: *Human Mental Workload*. Ed. by Peter A. Hancock and Najmedin Meshkati. Vol. 52. North-Holland, pp. 139–183. DOI: 10.1016/S0166-4115(08)62386-9.

Catherine Harvey, Neville A. Stanton, Carl A. Pickering, Mike McDonald, and Pengjun Zheng (2011). In-Vehicle Information Systems to Meet the Needs of Drivers. In: *International Journal of Human-Computer Interaction* 27.6, pp. 505–522. DOI: 10.1080/10447318.2011.555296.

Marc Hassenzahl, Michael Burmester, and Franz Koller (2003). AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In: *Mensch & Computer 2003: Interaktion in Bewegung*. (Stuttgart). Ed. by Gerd Szwillus and Jürgen Ziegler. B. G. Teubner: Stuttgart, pp. 187–196. ISBN: 3-519-00441-0. URL: http://dl.mensch-und-computer.de/handle/123456789/624.

Peter A. Heeman, Tomer Meshorer, Andrew L. Kun, Oskar Palinko, and Zeljko Medenica (2013). Estimating Cognitive Load Using Pupil Diameter During a Spoken Dialogue Task. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 242–245. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516570.

Niels Henze and Martin Pielot (2013). App Stores: External Validity for Mobile HCI. In: *interactions* 20.2 (Mar. 2013), pp. 33–38. ISSN: 1072-5520. DOI: 10.1145/2427076.2427084.

Niels Henze, Martin Pielot, Benjamin Poppinga, Torben Schinke, and Susanne Boll (2011). My App is an Experiment: Experience from User Studies in Mobile App Stores. In: *International Journal of Mobile Human Computer Interaction* 3.4 (Nov. 2011), pp. 71–91. DOI: 10.4018/jmhci.2011100105.

Paul Holleis, Friederike Otto, Heinrich Hussmann, and Albrecht Schmidt (2007). Keystroke-Level Model for Advanced Mobile Phone Interaction. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '07. San Jose, CA, USA). ACM: New York, NY, USA, pp. 1504–1514. ISBN: 978-1-59593-593-9. DOI: 10.1145/1240624.1240851.

Paul Holleis and Albrecht Schmidt (2008). MakeIt: Integrate User Interaction Times in the Design Process of Mobile Applications. English. In: *Pervasive Computing*. Ed. by Jadwiga Indulska, Donald J. Patterson, Tom Rodden, and Max Ott. Vol. 5013. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 56–74. ISBN: 978-3-540-79575-9. DOI: 10.1007/978-3-540-79576-6_4.

Zhang Hua and Wei Lieh Ng (2010). Speech Recognition Interface Design for In-Vehicle System. In: *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '10. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 29–33. ISBN: 978-1-4503-0437-5. DOI: 10.1145/1969773.1969780.

Human Performance Research Group (n.d.). *NASA Task Load Index (TLX). Paper and Pencil Package*. v 1.0. NASA Ames Research Center. Moffet Field, CA, USA. URL: http://humansystems.arc.nasa.gov/groups/tlx/downloads/TLX.pdf.

International Organization for Standardization (1975). ISO 3409:1975 Passenger Cars – Lateral Spacing of Foot Controls. ISO 3409:1975. Geneva, Switzerland.

International Organization for Standardization (1996). ISO 3958:1996 Passenger Cars – Driver Hand-Control Reach. ISO 3958:1996. Geneva, Switzerland, Mar. 1996.

International Organization for Standardization (2002). ISO 15005:2002 Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems – Dialogue Management Principles and Compliance Procedures. ISO 15006:2002. Geneva, Switzerland.

International Organization for Standardization (2004). Road vehicles – Ergonomic Aspects of Transport Information and Control Systems – Occlusion Method to Assess Visual Demand due to the Use of In-Vehicle Systems Control Systems (TICS) – Procedures for Determining Priority of On-Board Messages Presented to Drivers. ISO/TS 16951:2004. International Organization for Standardization: Geneva, Switzerland.

International Organization for Standardization (2007). Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems – Occlusion Method to Assess Visual Demand due to the Use of In-Vehicle Systems. ISO 16673:2007. International Organization for Standardization: Geneva, Switzerland.

International Organization for Standardization (2010a). ISO 2575:2010 Road vehicles – Symbols for Controls, Indicators and Tell-Tales. ISO 2575:2010. Geneva, Switzerland, 2010.

International Organization for Standardization (2010b). Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems – Simulated

Lane Change Test to assess in-vehicle secondary task demand. ISO 26022:2010. International Organization for Standardization: Geneva, Switzerland, 2010.

International Organization for Standardization (2014). ISO/TS 15007-2:2014 Road Vehicles – Measurement of Driver Visual Behaviour with Respect to Transport Information and Control Systems – Part 2: Equipment and Procedures. ISO/TS 15007-2:2014. Geneva, Switzerland, Aug. 2014.

International Organization for Standardization (2015). Road vehicles – Transport Information and Control Systems – Detection-Response Task (DRT) for Assessing Attentional Effects of Cognitive Load in Driving. ISO/DIS 17488. Under develpment. Geneva, Switzerland.

International Transport Forum (2015). *Automated and Autonomous Driving - Regulation Under Uncertainty*. Corporate Partnership Report. Paris, France: International Transport Forum, May 2015. URL: http://www.internationaltransportforum.org/Pub/pdf/15CPB_AutonomousDriving.pdf.

Shamsi T. Iqbal, Eric Horvitz, Yun-Cheng Ju, and Ella Mathews (2011). Hang on a Sec!: Effects of Proactive Mediation of Phone Conversations While Driving. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '11. Vancouver, BC, Canada). ACM: New York, NY, USA, pp. 463–472. ISBN: 978-1-4503-0228-9. DOI: 10.1145/1978942.1979008.

Shamsi T. Iqbal, Yun-Cheng Ju, and Eric Horvitz (2010). Cars, Calls, and Cognition: Investigating Driving and Divided Attention. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '10. Atlanta, GA, USA). ACM: New York, NY, USA, pp. 1281–1290. ISBN: 978-1-60558-929-9. DOI: 10.1145/1753326.1753518.

Tobias Islinger, Thorsten Köhler, and Christian Wolff (2011). Human Modeling in a Driver Analyzing Context: Challenge and Benefit. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 99–104. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381432.

Georg Jahn, Astrid Oehme, Josef F. Krems, and Christhard Gelau (2005). Peripheral Detection as a Workload Measure in Driving: Effects of Traffic Complexity and Route Guidance System Use in a Driving Study. In: *Transportation Research Part F: Traffic Psychology and Behaviour* 8.3, pp. 255–275. ISSN: 1369-8478. DOI: 10.1016/j.trf.2005.04.009.

Alejandro Jaimes and Nicu Sebe (2007). Multimodal Human-Computer Interaction: A Survey. In: *Computer Vision and Image Understanding* 108.1–2. Special Issue on Vision for Human-Computer Interaction, pp. 116–134. ISSN: 1077-3142. DOI: 10.1016/j.cviu.2006.10.019.

Japan Automobile Manufactures Association (2004). *JAMA: Guideline for In-Vehicle Display Systems - Version 3.0*. Tech. rep. Japan Automobile Manufactures Association, Aug. 2004.

Volker Johanning and Roman Mildner (2015). Beispiele von Car IT-Funktionen bei Premiumherstellern. German. In: *Car IT kompakt*. Springer Fachmedien Wiesbaden, pp. 45–59. ISBN: 978-3-658-09967-1. DOI: 10.1007/978-3-658-09968-8_3.

Willie D. Jones (2002). Building Safer Cars. In: *IEEE Spectrum* 39.1 (Jan. 2002), pp. 82–85. ISSN: 0018-9235. DOI: 10.1109/6.975028.

Younghee Jung, Per Persson, and Jan Blom (2005). DeDe: Design and Evaluation of a Context-enhanced Mobile Messaging System. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '05. Portland, OR, USA). ACM: New York, NY, USA, pp. 351–360. ISBN: 1-58113-998-5. DOI: 10.1145/1054972.1055021.

Daniel Kahneman (1973). *Attention and Effort*. Prentice-Hall series in Experimental Psychology. Prentice-Hall: Englewood Cliffs, NJ, USA. ISBN: 9780130505187.

Daniel Kahneman and Jackson Beatty (1966). Pupil Diameter and Load on Memory. In: *Science* 154.3756, pp. 1583–1585. DOI: 10.1126/science.154.3756.1583.

Daniel Kahneman, Linda Onuska, and Ruth E. Wolman (1968). Effects of Grouping on the Pupillary Response in a Short-Term Memory Task. In: *Quarterly Journal of Experimental Psychology* 20.3. PMID: 5683772, pp. 309–311. DOI: 10.1080/14640746808400168.

J-F Kamp, J-F. Forzy, C. Marin-Lamellet, and D. Causeur (2001). HMI Aspects of the Usability of Internet Services with an In-Car Terminal on a Driving Simulator. In: *IATSS Research* 25.2, pp. 29–39. ISSN: 0386-1112. DOI: 10.1016/S0386-1112(14)60068-6.

Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. In: *The International Journal of Aviation Psychology* 3.3, pp. 203–220. DOI: 10.1207/s15327108ijap0303_3.

Dagmar Kern, Angela Mahr, Sandro Castronovo, Albrecht Schmidt, and Christian Müller (2010). Making Use of Drivers' Glances Onto the Screen for Explicit Gaze-Based Interaction. In: *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '10. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 110–116. ISBN: 978-1-4503-0437-5. DOI: 10.1145/1969773.1969792.

Dagmar Kern, Paul Marshall, and Albrecht Schmidt (2010). Gazemarks: Gaze-based Visual Placeholders to Ease Attention Switching. In: *Proceedings of* *the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '10. Atlanta, GA, USA). ACM: New York, NY, USA, pp. 2093–2102. ISBN: 978-1-60558-929-9. DOI: 10.1145/1753326.1753646.

Dagmar Kern and Bastian Pfleging (2013). Supporting Interaction Through Haptic Feedback in Automotive User Interfaces. In: *interactions* 20.2 (Mar. 2013), pp. 16–21. ISSN: 1072-5520. DOI: 10.1145/2427076.2427081.

Dagmar Kern and Albrecht Schmidt (2009). Design Space for Driver-based Automotive User Interfaces. In: *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '09. Essen, Germany). ACM: Essen, Germany, pp. 3–10. ISBN: 978-1-60558-571-0. DOI: 10.1145/1620509.1620511.

Dagmar Kern, Albrecht Schmidt, Michael Pitz, and Klaus Bengler (2007). Status- und Kontextinformationen für die Telekommunikation im Auto. In: *Mensch & Computer 2007: Interaktion im Plural*. (Mensch & Computer 2007. Weimar, Germany). Ed. by Tom Gross. Oldenbourg Wissenschaftsverlag: München, pp. 119–128. DOI: 10.1524/9783486845488-015.

Dagmar Kern and Stefan Schneegass (2009). CARS - Configurable Automotive Research Simulator. In: *i-com* 8.2, pp. 30–33. ISSN: 1618-162X. DOI: 10.1524/icom.2009.0022.

Ashraf Khalil and Kay Connelly (2006). Context-Aware Telephony: Privacy Preferences and Sharing Patterns. In: *Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work*. (CSCW '06. Banff, AB, Canada). ACM: New York, NY, USA, pp. 469–478. ISBN: 1-59593-249-6. DOI: 10.1145/1180875.1180947.

Katja Kircher (2007). *Driver Distraction: A Review of the Literature*. Tech. rep. VTI rapport 594A. vti.

Wayne K. Kirchner (1958). Age Differences in Short-Term Retention of Rapidly Changing Information. In: *Journal of Experimental Psychology* 55.4 (Apr. 1958), pp. 352–358. DOI: 10.1037/h0043688.

Gwendolin Knappe, Andreas Keinath, and Cristina Meinecke (2008). Die Sensitivität verschiedener Maße zur Fahrzeugquerregelung im Vergleich. In: *Fortschritte der Verkehrspsychologie*. Ed. by Jens Schade and Arnd Engeln. VS Verlag für Sozialwissenschaften, pp. 237–256. ISBN: 978-3-531-15956-0. DOI: 10.1007/978-3-531-90949-3_12.

Arthur F. Kramer (1990). *Physiological Metrics of Mental Workload: A Reviw of Recent Progress*. Tech. rep. ADA223701. San Diego, CA, USA: Navy Personnel Research and Development Center, June 1990. URL: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA223701.

Andrew L. Kun, Susanne Boll, and Albrecht Schmidt (2016). Shifting Gears: User Interfaces in the Age of Autonomous Driving. In: *IEEE Pervasive Computing* 15.1 (Jan. 2016), pp. 32–38. ISSN: 1536-1268. DOI: 10.1109/MPRV.2016.14.

Andrew L. Kun and Zeljko Medenica (2012). Video Call, or Not, That is the Question. In: *CHI '12 Extended Abstracts on Human Factors in Computing Systems*. (CHI EA '12. Austin, TX, USA). ACM: New York, NY, USA, pp. 1631–1636. ISBN: 978-1-4503-1016-1. DOI: 10.1145/2212776.2223684.

Andrew L. Kun, Oskar Palinko, Zeljko Medenica, and Peter A. Heeman (2013). On the Feasibility of Using Pupil Diameter to Estimate Cognitive Load Changes for In-Vehicle Spoken Dialogues. In: *Proceedings of the Annual Conference of the International Speech Communication Association*. (INTERSPEECH '13. Lyon, France). International Speech and Communication Association, pp. 3766–3770.

Andrew L. Kun, Oskar Palinko, and Ivan Razumenić (2012). Exploring the Effects of Size and Luminance of Visual Targets on the Pupillary Light Reflex. In: *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '12. Portsmouth, NH, USA). ACM: New York, NY, USA, pp. 183–186. ISBN: 978-1-4503-1751-1. DOI: 10.1145/2390256.2390287.

Eric Laurier, Hayden Lorimer, Barry Brown, Owain Jones, Oskar Juhlin, Allyson Noble, Mark Perry, Daniele Pica, Philippe Sormani, Ignaz Strebel, Laurel Swan, Alex S. Taylor, Laura Watts, and Alexandra Weilenmann (2008). Driving and 'Passengering': Notes on the Ordinary Organization of Car Travel. In: *Mobilities* 3.1, pp. 1–23. DOI: 10.1080/17450100701797273.

Holger Lietz, Tibor Petzoldt, Matthias Henning, Juliane Haupt, Gerd Wanielik, Josef Krems, Henning Mosebach, Jan Schomerus, Martin Baumann, and Ulf Noyer (2011). *Methodische und technische Aspekte einer Naturalistic Driving Study*. FAT-Schriftenreihe 229. Forschungsvereinigung Automobiltechnik e.V.

Y. Lin, H. Leng, G. Yang, and H. Cai (2007). An Intelligent Noninvasive Sensor for Driver Pulse Wave Measurement. In: *IEEE Sensors Journal* 7.5 (May 2007), pp. 790–799. ISSN: 1530-437X. DOI: 10.1109/JSEN.2007.894923.

Walter Linderer (1951). Einrichtung zum Schutze von in Fahrzeugen befindlichen Personen gegen Verletzungen bei Zusammenstoessen. German. DE000000896312B. Oct. 1951. URL: https://depatisnet.dpma.de/DepatisNet/depatisnet?action=bibdat&docid=DE000000896312B.

Janne Lindqvist and Jason Hong (2011). Undistracted Driving: A Mobile Phone That Doesn'T Distract. In: *Proceedings of the 12th Workshop on Mobile Computing Systems and Applications*. (HotMobile '11. Phoenix, AZ, USA). ACM: New York, NY, USA, pp. 70–75. ISBN: 978-1-4503-0649-2. DOI: 10.1145/2184489.2184504.

Allan Christian Long Jr., James A. Landay, and Lawrence A. Rowe (1999). Implications for a Gesture Design Tool. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '99. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 40–47. ISBN: 0-201-48559-1. DOI: 10.1145/302979.302985.

Lennart S. Lutz, Tito Tang, and Markus Lienkamp (2012). Analyse der rechtlichen Situation von teleoperierten (und autonomen) Fahrzeugen. In: *5. Tagung Fahrerassistenz*. (5. Tagung Fahrerassistenz. Munich, Germany).

Jannette Maciej and Mark Vollrath (2009). Comparison of Manual vs. Speech-Based Interaction with In-Vehicle Information Systems. In: *Accident Analysis & Prevention* 41.5, pp. 924–930. ISSN: 0001-4575. DOI: 10.1016/j.aap.2009.05.007.

Punitha Manalavan, Asad Samar, Mike Schneider, Sara Kiesler, and Dan Siewiorek (2002). In-Car Cell Phone Use: Mitigating Risk by Signaling Remote Callers. In: *CHI '02 Extended Abstracts on Human Factors in Computing Systems*. (CHI EA '02. Minneapolis, MN, USA). ACM: New York, NY, USA, pp. 790–791. ISBN: 1-58113-454-1. DOI: 10.1145/506443.506599.

Daniel Manes, Paul A. Green, and David Hunter (1997). *Prediction of Destination Entry and Retrieval Times Using Keystroke-Level Models*. Tech. rep. UMTRI-96-37. Ann Arbor, MI, USA: The University of Michigan Transportation Research Institute (UMTRI), Dec. 1997.

Natalia Marmasse (1999). comMotion: A Context-aware Communication System. In: *CHI '99 Extended Abstracts on Human Factors in Computing Systems*. (CHI EA '99. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 320–321. ISBN: 1-58113-158-5. DOI: 10.1145/632716.632910.

Sandra P. Marshall (2002). The Index of Cognitive Activity: Measuring Cognitive Workload. In: *Proceedings of the IEEE 7th Conference on Human Factors and Power Plants*. (Scottsdale, AZ, USA), pp. 7-5–7-9. ISBN: 0-7803-7450-9. DOI: 10.1109/HFPP.2002.1042860.

Marieke H. Martens and Arie Paul van den Beukel (2013). The Road to Automated Driving: Dual Mode and Human Factors Considerations. In: *16th International IEEE Conference on Intelligent Transportation Systems*. (ITSC 2013). Oct. 2013, pp. 2262–2267. DOI: 10.1109/ITSC.2013.6728564.

Marieke H. Martens and W. van Winsum (2000). Measuring Distraction: the Peripheral Distraction Task. In: *Proceedings NHTSA: Internet Forum on the safety impact of driver distraction when using in-vehicle technologies*. (Driver Distraction Internet Forum Driver Distraction Internet Forum Driver Distraction Internet Forum). U.S. Department of Transportation, National Highway Traffic Safety Administration. URL: http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/34.pdf.

Stefan Mattes (2003). The Lane-Change-Task as a Tool for Driver Distraction Evaluation. In: *Quality of Work and Products in Enterprises of the future: Proceedings of the Annual Spring Conference of the GfA on the Occasion of the 50th Anniversary of the Foundation of the Gesellschaft für Arbeitswissenschaft e.V. (GfA) and the XVII Anual Conference of the International Society for Occupational Ergonomics & Safety (ISOES)*. (Annual Spring Conference of the GfA / ISOES. Munich, Germany). Ed. by Helmut Strasser, Karsten Kluth, Herbert Rausch, and Heiner Bubb. Ergonomics. Ergonomia Verlag: Stuttgart, Germany, May 2003, pp. 57–60. ISBN: 3-935089-68-6.

Stefan Mattes and Anders Hallén (2008). Surrogate Distraction Measurement Techniques: The Lane Change Test. In: *Driver Distraction: Theory, Effects, and Mitigation*. Ed. by Kristie Young, John D. Lee, and Michael A. Regan. CRC Press: Boca Raton, FL, USA. Chap. 8, pp. 107–122. ISBN: 9780849374265. DOI: 10.1201/9781420007497.ch8.

Max-Emanuel Maurer (2013). *likertplot.com – Plot Likert Scales*. URL: http://www.likertplot.com/.

Bruce Mehler, Bryan Reimer, Joseph F. Coughlin, and Jeffery Dusek (2009). Impact of Incremental Increases in Cognitive Workload on Physiological Arousal and Performance in Young Adult Drivers. In: *Transportation Research Record: Journal of the Transportation Research Board* 2138, pp. 6–12. DOI: 10.3141/2138-02.

Bruce Mehler, Bryan Reimer, and Jeffery A. Dusek (2011). *MIT AgeLab Delayd Digit Recall Taks (n-back)*. WhitePaper 2011-3B. Cambridge, MA, USA: MIT AgeLab - Massachusetts Institute of Technology. URL: http://agelab.mit.edu/system/files/Mehler_et_al_n-back-white-paper_2011_B.pdf.

Bruce Mehler, Bryan Reimer, and Marin Zec (2012). Defining Workload in the Context of Driver State Detection and HMI Evaluation. In: *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '12. Portsmouth, NH, USA). ACM: New York, NY, USA, pp. 187–191. ISBN: 978-1-4503-1751-1. DOI: 10.1145/2390256.2390288.

Natasha Merat and A. Hamish Jamson (2007). Multisensory Signal Detection: How does Driving and IVIS Management Affect Performance? In: *Proceedings of the Fourth International Driving Symposium on Hu man Factors in Driver Assessment, Training and Vehicle Design*. (Stevenson, WA, USA), pp. 351–357. URL: http://drivingassessment.uiowa.edu/DA2007/PDF/059_MeratJamson.pdf.

N. Meshkati (1988). Heart Rate Variability and Mental Workload Assessment. In: *Human Mental Workload*. Ed. by Peter A. Hancock and Najmedin Meshkati.

Vol. 52. Advances in Psychology. North-Holland, pp. 101–115. DOI: 10.1016/S0166-4115(08)62384-5.

Richard M. Michaels (1962). Effect of Expressway Design on Driver Tension Responses. In: *Highway Research Board Bulletin*.

Allen E. Milewski and Thomas M. Smith (2000). Providing Presence Cues to Telephone Users. In: *Proceedings of the 2000 ACM Conference on Computer Supported Cooperative Work*. (CSCW '00. Philadelphia, PA, USA). ACM: New York, NY, USA, pp. 89–96. ISBN: 1-58113-222-0. DOI: 10.1145/358916.358978.

Sarah Miller (2001). *Literature Review. Workload Measures*. Tech. rep. N01-006. National Advanced Driving Similator, Iowa City, IA, USA: University of Iowa, Aug. 2001. URL: http://www.nads-sc.uiowa.edu/publicationStorage/200501251347060.N01-006.pdf.

W. Thomas Miller and Andrew L. Kun (2013). Using Speech, GUIs and Buttons in Police Vehicles: Field Data on User Preferences for the Project54 System. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 108–113. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516564.

Eve Mitsopoulos-Rubens, Margaret J. Trotter, and Michael G. Lenné (2011). Effects on Driving Performance of Interacting With an In-Vehicle Music Player: A Comparison of Three Interface Layout Concepts for Information Presentation. In: *Applied Ergonomics* 42.4. Applied Ergonomics and Transportation Safety, pp. 583–591. ISSN: 0003-6870. DOI: 10.1016/j.apergo.2010.08.017.

Bela Mittelmann and Harold G. Wolff (1939). Affective States and Skin Temperature: Experimental Study of Subjects with "Cold Hands" and Raynaud's Syndrome. In: *Psychosomatic Medicine* 1.2, pp. 271–292. URL: http://www.psychosomaticmedicine.org/content/1/2/271.abstract.

T. Miura (1986). Coping with Situational Demands: A Study of Eye Movements and Peripheral Vision Performance. In: *Proceedings of Vision in Vehicles*. (N/A). Ed. by A. G. Gale, I. D. Brown, C. M. Haslegrave, P. Smith, and S. Taylor. Elsevier: Amsterdam, The Netherlands, pp. 205–216.

Rolf Molich and Jakob Nielsen (1990). Improving a Human-Computer Dialogue. In: *Commun. ACM* 33.3 (Mar. 1990), pp. 338–348. ISSN: 0001-0782. DOI: 10.1145/77481.77486.

C. Müller and G. Weinberg (2011). Multimodal Input in the Car, Today and Tomorrow. In: *IEEE MultiMedia* 18.1 (Jan. 2011), pp. 98–103. ISSN: 1070-986X. DOI: 10.1109/MMUL.2011.14.

Michael Myrtek, Doris Weber, Georg Brügner, and Wolfgang Müller (1996). Occupational Stress and Strain of Female Students: Results of Physiological, Behavioral, and Psychological Monitoring. In: *Biological Psychology* 42.3. Psychophysiology of Workload, pp. 379–391. ISSN: 0301-0511. DOI: 10.1016/0301-0511(95)05168-6.

Vicki L. Neale, Thomas A. Dingus, Sheila G. Klauer, Jeremy Sudweeks, and Michael Goodman (2005). *An Overview of the 100-Car Naturalistic Study and Findings*. National Highway Traffic Safety Administration, Paper Number 05-0400. URL: http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2005/100Car_ESV05summary.pdf.

Vicky L. Neale, Shiela G. Klauer, R. R. Knipling, Thomas A. Dingus, G. T. Holbrook, and A. Petersen (2002). *The 100 Car Naturalistic Driving Study, Phase 1 – Experimental Design*. Tech. rep. DOT HS 809 536. Washington, DC, USA: National Highway Transportation Safety Administration, Dec. 2002. URL: http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2002/100CarPhase1Report.pdf.

Les Nelson, Sara Bly, and Tomas Sokoler (2001). Quiet Calls: Talking Silently on Mobile Phones. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '01. Seattle, WA, USA). ACM: New York, NY, USA, pp. 174–181. ISBN: 1-58113-327-8. DOI: 10.1145/365024.365094.

Glen Nicholson (2007). Electronic Stability Control (ESC). In: *The Official Newsletter of the Canadian Association of Road Safety Profesionals* 2007.3, pp. 1–5. URL: http://dmv.dot.gov.nt.ca/sites/default/files/Electronic%20Stability.pdf.

Thomas E. Nygren (1991). Psychometric Properties of Subjective Workload Measurement Techniques: Implications for Their Use in the Assessment of Perceived Mental Workload. In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 33.1, pp. 17–33. DOI: 10.1177/001872089103300102.

S. Olsson and P. C. Burns (2000). Measuring Driver Visual Distraction with a Peripheral Detection Task. In: *Proceedings NHTSA: Internet Forum on the safety impact of driver distraction when using in-vehicle technologies*. (Driver Distraction Internet Forum). U.S. Department of Transportation, National Highway Traffic Safety Administration. URL: http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/6.PDF.

Calvin K. L. Or and Vincent G. Duffy (2007). Development of a Facial Skin Temperature-Based Methodology for Non-Intrusive Mental Workload Measurement. In: *Occupational Ergonomics* 7.2, pp. 83–94. ISSN: 1875-9092. URL: http://content.iospress.com/journals/occupational-ergonomics/7/2.

Sharon Oviatt (2012). Multimodal Interfaces. In: *Human-Computer Interaction Handbook*. Ed. by Julie A. Jacko. Third Edition. CRC Press: Boca Raton, FL, USA. Chap. 18, pp. 405–430. ISBN: 978-1-4398-2943-1. DOI: doi:10.1201/b11963-22.

Claudio E Palazzi, Marco Roccetti, Stefano Ferretti, Giovanni Pau, and Mario Gerla (2007). Online Games on Wheels: Fast Game Event Delivery in Vehicular Ad-Hoc Networks. In: *Proceedings of the Third Intrenational Workshop on Vehicle-to-Vehicle Communications*. (V2VCOM 2007. Istanbul, Turkey). June 2007.

Oskar Palinko and Andrew L. Kun (2011). Exploring the Influence of Light and Cognitive Load on Pupil Diameter in Driving Simulator Studies. In: *Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. (DA '11. Lake Tahoe, CA, USA), pp. 329–336. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2011/Papers/048_PalinkoKun.pdf.

Oskar Palinko and Andrew L. Kun (2012). Exploring the Effects of Visual Cognitive Load and Illumination on Pupil Diameter in Driving Simulators. In: *Proceedings of the Symposium on Eye Tracking Research and Applications*. (ETRA '12. Santa Barbara, CA, USA). ACM: New York, NY, USA, pp. 413–416. ISBN: 978-1-4503-1221-9. DOI: 10.1145/2168556.2168650.

Oskar Palinko, Andrew L. Kun, Alexander Shyrokov, and Peter Heeman (2010). Estimating Cognitive Load Using Remote Eye Tracking in a Driving Simulator. In: *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications*. (ETRA '10. Austin, TX, USA). ACM: New York, NY, USA, pp. 141–144. ISBN: 978-1-60558-994-7. DOI: 10.1145/1743666.1743701.

Annie Pauzié (2008). A Method to Assess the Driver Mental Workload: The Driving Activity Load Index (DALI). In: *Intelligent Transport Systems, IET* 2.4 (Dec. 2008), pp. 315–322. ISSN: 1751-956X. DOI: 10.1049/iet-its:20080023.

Annie Pauzié (2014). Evaluation of the Driver's Mental Workload: A Necessity in a Perspective of In-Vehicle System Design for Road Safety Improvement. In: *Cognition, Technology & Work* 16.3, pp. 299–302. ISSN: 1435-5558. DOI: 10.1007/s10111-014-0276-0.

Matthias Peissner, Vanessa Doebler, and Florian Metze (2011). *Can Voice Interaction Help Reducing the Level of Distraction and Prevent Accidents? Meta-Study on Driver Distraction and Voice Interaction*. White Paper. Stuttgart, Germany: Fraunhofer-Institute for Industrial Engineering and Carnegie Mellon University, May 2011. URL: http://wiki.iao.fraunhofer.de/images/studien/driver-distraction-and-voice-interaction.pdf.

Miguel Perez, Melissa Hulse, and Linda Angell (2013). *Support for NHTSA Visual-Manual Guidelines: Expert Review of the Visual Occlusion Method and How it Compares to Driver Eye-Glance Behavior*. Tech. rep. DOT HS 811 763. Washington, DC, USA: National Highway Transportation Safety Administration, May 2013.

Celine Pering (2002). Taming of the Ring: Context Specific Social Mediation for Communication Devices. In: *CHI '02 Extended Abstracts on Human Factors in Computing Systems*. (CHI EA '02. Minneapolis, MN, USA). ACM: New York, NY, USA, pp. 712–713. ISBN: 1-58113-454-1. DOI: 10.1145/506443.506560.

Michael Pettitt, Gary Burnett, and Alan Stevens (2005). Defining Driver Distraction. In: *Proceedings of the 12th World Congress on Intelligent Transport Systems*. (12th World Congress on Intelligent Transport Systems. San Francisco, CA, USA). PA-TR-4224-05.

Michael Pettitt, Gary Burnett, and Alan Stevens (2007). An Extended Keystroke Level Model (KLM) for Predicting the Visual Demand of In-vehicle Information Systems. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '07. San Jose, CA, USA). ACM: New York, NY, USA, pp. 1515–1524. ISBN: 978-1-59593-593-9. DOI: 10.1145/1240624.1240852.

Bastian Pfleging, Tanja Döring, Michael Kienast, and Albrecht Schmidt (2011). SpeeT: A Multimodal Interaction Style Combining Speech and Touch Interaction in Automotive Environments. In: *Adjunct Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria), pp. 65–66. URL: http://www.auto-ui.org/11/docs/AUI2011_adjunctproceedings.pdf#page=65.

Bastian Pfleging, Drea K. Fekety, Albrecht Schmidt, and Andrew L. Kun (2016). A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. (CHI '16. San Jose, CA, USA). ACM: New York, NY, USA, May 2016, pp. 5776–5788. DOI: 10.1145/2858036.2858117.

Bastian Pfleging, Alireza Sahami, Marvin Steinberg, and Albrecht Schmidt (2011). Towards an Application Platform that Allows Access to Sensors in the Car. In: *Proceedings of the CHI '11 Workshop on Data Collection by the People, for the People*. (Vancouver, BC, Canada). Vancouver, BC, Canada.

Bastian Pfleging and Albrecht Schmidt (2015). (Non-) Driving-Related Activities in the Car: Defining Driver Activities for Manual and Automated Driving. In: *Workshop on Experiencing Autonomous Vehicles: Crossing the Boundaries between a Drive and a Ride at CHI '15*. (Seoul, South Korea).

Bastian Pfleging, Stefan Schneegass, and Albrecht Schmidt (2012). Multimodal Interaction in the Car: Combining Speech and Gestures on the Steering Wheel. In: *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '12. Portsmouth, NH, USA). ACM: New York, NY, USA, pp. 155–162. ISBN: 978-1-4503-1751-1. DOI: 10.1145/2390256.2390282.

Bastian Pfleging, Stefan Schneegass, and Albrecht Schmidt (2013). Exploring User Expectations for Context and Road Video Sharing While Calling and

Drivings. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 132–139. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516547.

Carl A. Pickering, Keith J. Burnham, and Michael J. Richardson (2007). A Research Study of Hand Gesture Recognition Technologies and Applications for Human Vehicle Interaction. In: *Proceedings of the 3rd Institution of Engineering and Technology Conference on Automotive Electronics*. (IET Automotive Electronics '07). June 2007.

Carl A. Pickering, K.J. Burnham, and M.J. Richardson (2007). A Review of Automotive Human Machine Interface Technologies and Techniques to Reduce Driver Distraction. In: *2nd Institution of Engineering and Technology International Conference on System Safety*. (London, United Kingdom). Oct. 2007, pp. 223–228. ISBN: 978-0-86341-863-1.

Monika Pilgerstorfer, Kerstin Runda, Christian Brandstätter, Michiel Christoph, Shalom Hakkert, Tomer Toledo, Robert Ishaq, and Michael Gatscha (2011). *Small Scale Naturalistic Driving Pilot, Deliverable 6.3 of the EC FP7 project DaCoTA*. Tech. rep. Kuratorium für Verkehrssicherheit. URL: http://dacota-project.eu/Deliverables/DaCoTA_D6%203_Report%20on%20Small%20scale%20ND%20pilot%20Final_20120625.pdf.

Ming-Zher Poh, Daniel J. McDuff, and Rosalind W. Picard (2010). Non-Contact, Automated Cardiac Pulse Measurements Using Video Imaging and Blind Source Separation. In: *Optics Express* 18.10 (May 2010), pp. 10762–10774. DOI: 10.1364/OE.18.010762.

Ming-Zher Poh, Daniel J. McDuff, and Rosalind W. Picard (2011). Advancements in Noncontact, Multiparameter Physiological Measurements Using a Webcam. In: *IEEE Transactions on Biomedical Engineering* 58.1 (Jan. 2011), pp. 7–11. ISSN: 0018-9294. DOI: 10.1109/TBME.2010.2086456.

Ioannis Politis, Stephen Brewster, and Frank Pollick (2015). Language-Based Multimodal Displays for the Handover of Control in Autonomous Cars. In: *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '15. Nottingham, United Kingdom). ACM: New York, NY, USA, pp. 3–10. ISBN: 978-1-4503-3736-6. DOI: 10.1145/2799250.2799262.

Bernhard Preim and Raimund Dachselt (2010). *Interaktive Systeme. Band 1: Grundlagen, Graphical User Interfaces, Informationsvisualisierung*. 2. Auflage. eXamen.press. Springer Berlin Heidelberg: Berlin and Heidelberg, Germany. ISBN: 978-3-642-05402-0. DOI: 10.1007/978-3-642-05402-0.

Bernhard Preim and Raimund Dachselt (2015). *Interaktive Systeme. Band 2: User Interface Engineering, 3D-Interaktion, Natural User Interfaces*. 2. Auflage.

eXamen.press. Springer Berlin Heidelberg: Berlin and Heidelberg, Germany. ISBN: 978-3-642-45247-5. DOI: 10.1007/978-3-642-45247-5.

Heinrich K.H. Prinz von Preuszen (1908). Aus einem nach Art eines Freiträgers ausladenden Abstreichlineal bestehender Scheibenreiniger für die vordere Schutzscheibe an Kraftfahrzeugen. German. DE204343. Mar. 1908. URL: http://www.dpma.de/docs/service/klassifikationen/ipc/auto_ipc/de204343a.pdf.

Jonas Radlmayr, Christian Gold, Lutz Lorenz, Mehdi Farid, and Klaus Bengler (2014). How Traffic Situations and Non-Driving Related Tasks Affect the Take-Over Quality in Highly Automated Driving. In: *Proc. HFES Annual Meeting* 58.1, pp. 2063–2067. DOI: 10.1177/1541931214581434.

Thomas A. Ranney, G. H. Scott Baldwin, Larry A. Smith, Elizabeth N. Mazzae, and Russell S. Pierce (2014). *Detection Response Task Evaluation for Driver Distraction Measurement Application*. Tech. rep. DOT HS 812 077. Washington, DC, USA: National Highway Transportation Safety Administration, Nov. 2014.

Thomas A. Ranney, W. Riley Garrott, and Michael J. Goodman (2001). NHTSA Driver Distraction Research: Past, Present, and Future. In: *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles*. (DOT HS 809 220. Amsterdam, The Netherlands). U.S. Department of Transportation, National Highway Traffic Safety Administration. URL: http://www-nrd.nhtsa.dot.gov/pdf/esv/esv17/proceed/00177.pdf.

James T. Reason (1978). Motion Sickness Adaptation: A Neural Mismatch Model. In: *Journal of the Royal Society of Medicine* 71.11, p. 819.

Donald A. Redelmeier and Robert J. Tibshirani (1997). Association Between Cellular-Telephone Calls and Motor Vehicle Collisions. In: *New England Journal of Medicine* 336.7. PMID: 9017937, pp. 453–458. DOI: 10.1056/NEJM199702133360701.

Matthew P. Reed and Paul A. Green (1999). Comparison of Driving Performance On-Road and in a Low-Cost Simulator Using a Concurrent Telephone Dialling Task. In: *Ergonomics* 42.8, pp. 1015–1037. DOI: 10.1080/001401399185117.

Leah M. Reeves, Jennifer Lai, James A. Larson, Sharon Oviatt, T. S. Balaji, Stéphanie Buisine, Penny Collings, Phil Cohen, Ben Kraal, Jean-Claude Martin, Michael McTear, TV Raman, Kay M. Stanney, Hui Su, and Qian Ying Wang (2004). Guidelines for Multimodal User Interface Design. In: *Communications of the ACM* 47.1 (Jan. 2004), pp. 57–59. ISSN: 0001-0782. DOI: 10.1145/962081.962106.

Michael A. Regan, Charlene Hallett, and Craig P. Gordon (2011). Driver Distraction and Driver Inattention: Definition, Relationship and Taxonomy. In: *Accident Analysis & Prevention* 43.5, pp. 1771–1781. ISSN: 0001-4575. DOI: 10.1016/j.aap.2011.04.008.

Gary B. Reid, F. Thomas Eggemeier, and Clark A. Shingledecker (1989). *Subjective Workload Assessment Technique*. Tech. rep. AAMRL-TR-89-023. Air Force Flight Test Center Edwards AFB, July 1989.

Gary B. Reid and Thomas E. Nygren (1988). The Subjective Workload Assement Technique: A Scaling Procedure for Measuring Mental Workload. In: *Human Mental Workload*. Ed. by Peter A. Hancock and Najmedin Meshkati. Vol. 52. Advances in Psychology. North-Holland, pp. 185–218. DOI: 10.1016/S0166-4115(08)62387-0.

Gary B. Reid, Clark A. Shingledecker, Thomas E. Nygren, and F. Thomas Eggemeier (1981). Development of Multidimensional Subjective Measures of Workload. In: *Proceedings of the IEEE International Conference on Cybernetics and Society*. (Atlanta, GA, USA). IEEE, pp. 403–406.

Bryan Reimer, Joseph F. Coughlin, and Bruce Mehler (2009). Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior. In: *Proceedings of ITS America*. (ITS America '09).

Andreas Riener, Alois Ferscha, and Mohamed Aly (2009). Heart on the Road: HRV Analysis for Monitoring a Driver's Affective State. In: *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '09. Essen, Germany). ACM: New York, NY, USA, pp. 99–106. ISBN: 978-1-60558-571-0. DOI: 10.1145/1620509.1620529.

Andreas Riener and Philipp Wintersberger (2011). Natural, Intuitive Finger Based Input As Substitution for Traditional Vehicle Control. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 159–166. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381442.

Hermann Rohling (2012). Car-to-Car Communications. In: *2012 International Symposium on Signals, Systems, and Electronics*. (ISSE. Potsdam, Germany). Oct. 2012, pp. 1–5. DOI: 10.1109/ISSSE.2012.6374299.

Barbara Rosario, Kent Lyons, and Jennifer Healey (2011). A Dynamic Content Summarization System for Opportunistic Driver Infotainment. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 95–98. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381431.

A. H. Roscoe and G. A. Ellis (1990). *A Subjective Rating Scale for Assessing Pilot Workload in Flight: a Decade of Practical Use*. Tech. rep. RAE TR 90019. Bedford, UK: Royal Aerospace Establishment, Mar. 1990. URL: http://www.dtic.mil/dtic/tr/fulltext/u2/a227864.pdf.

Alan H. Roscoe (1993). Heart Rate as a Psychophysiological Measure for In-Flight Workload Assessment. In: *Ergonomics* 36.9. PMID: 8404834, pp. 1055–1062. DOI: 10.1080/00140139308967977.

Christina M. Rudin-Brown and Heather A. Parker (2004). Behavioural Adaptation to Adaptive Cruise Control (ACC): Implications for Preventive Strategies. In: *Transportation Research Part F: Traffic Psychology and Behaviour* 7.2 (Mar. 2004), pp. 59–76. ISSN: 1369-8478. DOI: 10.1016/j.trf.2004.02.001.

Jaime Ruiz, Yang Li, and Edward Lank (2011). User-Defined Motion Gestures for Mobile Interaction. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '11. Vancouver, BC, Canada). ACM: New York, NY, USA, pp. 197–206. ISBN: 978-1-4503-0228-9. DOI: 10.1145/1978942.1978971.

Mark E. Russell, Clifford A. Drubin, Anthony S. Marinilli, W. Gordon Woodington, and Michael J. Del Checcolo (2002). Integrated Automotive Sensors. In: *IEEE Transactions on Microwave Theory and Techniques* 50.3 (Mar. 2002), pp. 674–677. ISSN: 0018-9480. DOI: 10.1109/22.989952.

SAE International (2002). Surface Vehicle Recommended Practice Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks SAE J2365. Proposed Draft. Warrendale, PA, USA, Apr. 2002. URL: http://www.umich.edu/~driving/documents/SAEJ2365_guidelines.pdf.

SAE International (2003). Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements. SAE J2400. Warrendale, PA, USA, Aug. 2003. URL: http://standards.sae.org/j2400_200308/.

SAE International (2004). SAE Recommended Practice Navigation and Route Guidance Function Accessibility While Driving (SAE 2364). Draft. Warrendale, PA, USA, Feb. 2004. URL: http://www.umich.edu/~driving/documents/SAEJ2364_guidelines.pdf.

SAE International (2007). Road/Lane Departure Warning Systems: Information for the Human Interface. SAE J2808. Warrendale, PA, USA, Aug. 2007. URL: http://standards.sae.org/j2808_200708/.

SAE International (2008a). ITS In-Vehicle Message Priority. SAE J2395. Warrendale, PA, USA, Feb. 2008. URL: http://standards.sae.org/j2395_200202/.

SAE International (2008b). Process for Comprehension Testing of In-Vehicle Icons. SAE J2830. Warrendale, PA, USA, July 2008. URL: http://standards.sae.org/j2830_200807/.

SAE International (2010). Blind Spot Monitoring System (BSMS): Operating Characteristics and User Interface. SAE J2802. Warrendale, PA, USA, Jan. 2010. URL: http://standards.sae.org/j2802_201001/.

SAE International (2013). Operational Definitions of Driving Performance Measures and Statistics. SAE J2944. Proposed Draft. Warrendale, PA, USA, Feb. 2013. URL: http://standards.sae.org/wip/j2944/.

SAE International (2014a). Adaptive Cruise Control (ACC) Operating Characteristics and User Interface. SAE J2399. Warrendale, PA, USA, Sept. 2014. URL: http://standards.sae.org/j2399_201409/.

SAE International (2014b). Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. SAE J3016_201401. Warrendale, PA, USA, Jan. 2014. URL: http://standards.sae.org/j3016_201401/.

SAE International (n.d.). Principles and Guidelines for Voice User Interfaces as a Driver Vehicle Interface. SAE J2988. Work-in-Progress, not yet published. Warrendale, PA, USA. URL: http://standards.sae.org/wip/j2988/.

Adella Santos, Nancy McGuckin, Hikari Yukiko Nakamoto, Danielle Gray, and Susan Liss (2011). *Summary of Travel Trends: 2009 National Household Travel Survey*. Tech. rep. FHWA-PL-11-022. Washington, DC, USA: Federal Highway Administration, U.S. Department of Transportation, June 2011. URL: http://nhts.ornl.gov/2009/pub/stt.pdf.

Roland Schindhelm, Christhard Gelau, Andreas Keinath, Klaus Bengler, Holger Kussmann, Paul Kompfner, Pietro Carlo Cacciabue, and Manuela Martinetto (2004). *Report on the Review of the Available Guidelines and Standards*. Tech. rep. IST-1-507674-IP D43.1. Information Society Technologies (IST) Programme - AIDE - Adaptive Integrated Driver-vehicle InterfacE. URL: http://www.aide-eu.org/pdf/sp4_deliv_new/aide_d4_3_1.pdf.

Albrecht Schmidt (2000). Implicit Human Computer Interaction Through Context. English. In: *Personal Technologies* 4.2-3, pp. 191–199. ISSN: 0949-2054. DOI: 10.1007/BF01324126.

Albrecht Schmidt, Antti Takaluoma, and Jani Mäntyjärvi (2000). Context-Aware Telephony over WAP. In: *Personal Technologies* 4.4, pp. 225–229. ISSN: 0949-2054. DOI: 10.1007/BF02391563.

Stefan Schneegass, Bastian Pfleging, Nora Broy, Frederik Heinrich, and Albrecht Schmidt (2013). A Data Set of Real World Driving to Assess Driver Workload. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 150–157. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516561.

Stefan Schneegass, Bastian Pfleging, Dagmar Kern, and Albrecht Schmidt (2011). Support for Modeling Interaction with Automotive User Interfaces. In: *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '11. Salzburg, Austria). ACM: New York, NY, USA, pp. 71–78. ISBN: 978-1-4503-1231-8. DOI: 10.1145/2381416.2381428.

Mike Schneider and Sara Kiesler (2005). Calling While Driving: Effects of Providing Remote Traffic Context. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '05. Portland, OR, USA). ACM: New York, NY, USA, pp. 561–569. ISBN: 1-58113-998-5. DOI: 10.1145/1054972.1055050.

Markus Schöttle (2014). „Keine unüberwindbaren Hürden beim automatisierten Fahren". Sicherheit - Car-IT - Konzepte. German. In: *Vernetztes Automobil*. Ed. by Wolfgang Siebenpfeiffer. ATZ/MTZ-Fachbuch. Springer Fachmedien Wiesbaden, pp. 64–67. ISBN: 978-3-658-04018-5. DOI: 10.1007/978-3-658-04019-2_9.

R. Sharma, M. Yeasin, N. Krahnstoever, I. Rauschert, Guoray Cai, I. Brewer, A.M. MacEachren, and K. Sengupta (2003). Speech-Gesture Driven Multimodal Interfaces for Crisis Management. In: *Proceedings of the IEEE* 91.9 (Sept. 2003), pp. 1327–1354. ISSN: 0018-9219. DOI: 10.1109/JPROC.2003.817145.

Ben Shneiderman, Catherine Plaisant, Maxine Cohen, and Steven Jacobs (2009). *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. 5th edition. Pearson. Chap. 2.3.4. ISBN: 9780321537355.

Society of Automotive Engineers (1974). Symbols for Motor Vehicle Controls, Indicators and Tell-Tales. Warrendale, PA, USA, Sept. 1974. URL: http://standards.sae.org/j1048_197409/.

Society of Automotive Engineers (1977). Direction-of-Motion Stereotypes for Automotive Hand Controls. Warrendale, PA, USA, Sept. 1977. URL: http://standards.sae.org/j1139_197709/.

Society of Automotive Engineers (1998). Recommended Practice - SAE J-2396 Definition and Experimental Measures Related to the Specification of Driver Visual Behavior Using Video Based Techniques. Draft. Warrendale, PA, USA, Dec. 1998. URL: http://apps.usd.edu/coglab/schieber/psyc707/pdf/sae-j2396b.pdf.

Timothy Sohn, Kevin A. Li, William G. Griswold, and James D. Hollan (2008). A Diary Study of Mobile Information Needs. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '08. Florence, Italy). ACM: New York, NY, USA, pp. 433–442. ISBN: 978-1-60558-011-1. DOI: 10.1145/1357054.1357125.

Erin T. Solovey, Marin Zec, Enrique Abdon Garcia Perez, Bryan Reimer, and Bruce Mehler (2014). Classifying Driver Workload Using Physiological and Driving Performance Data: Two Field Studies. In: *Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems*. (CHI '14.

Toronto, ON, Canada). ACM: New York, NY, USA, pp. 4057–4066. ISBN: 978-1-4503-2473-1. DOI: 10.1145/2556288.2557068.

Roland Spies, Andreas Blattner, Christian Lange, Martin Wohlfarter, Klaus Bengler, and Werner Hamberger (2011). Measurement of Driver's Distraction for an Early Prove of Concepts in Automotive Industry at the Example of the Development of a Haptic Touchpad. In: *Human-Computer Interaction. Interaction Techniques and Environments*. Ed. by Julie A. Jacko. Vol. 6762. Lecture Notes in Computer Science. Springer: Berlin and Heidelberg, pp. 125–132. ISBN: 978-3-642-21604-6. DOI: 10.1007/978-3-642-21605-3_14.

Statistisches Bundesamt (2014). Verkehr - Verkehrsunfälle. In: *Fachserie 8, Reihe 7* updated 02'2015 (Nov. 2014), pp. 1–50. URL: https://www.destatis.de/DE/Publikationen/Thematisch/TransportVerkehr/Verkehrsunfaelle/VerkehrsunfaelleMonat/VerkehrsunfaelleM2080700141114.pdf?__blob=publicationFile.

Tatjana Streit, Bastian Chlond, Christine Weiß, and Peter Vortisch (2014). *Deutsches Mobilitätspanel (MOP) - Wissenschaftliche Begleitung und Auswertungen Bericht 2013/2014: Alltagsmobilität und Fahrleistung*. Tech. rep. Karlsruher Institut für Technologie, Insitut für Verkehrswesen, Jan. 2014. URL: http://mobilitaetspanel.ifv.kit.edu/downloads/Bericht_MOP_13_14.pdf.

Jane C. Stutts, Donald W. Reinfurt, Loren Stapli, and Eric A. Rodgman (2001). *The Role of Driver Distraction in Traffic Crashes*. Washington, DC, May 2001. URL: https://www.aaafoundation.org/sites/default/files/distraction%20%281%29.pdf.

SWOV Institute for Road Safety Research (2012). *SWOV Fact Sheet: Naturalistic Driving: Observing Everyday Driving Behaviour*. Dec. 2012. URL: https://www.swov.nl/rapport/Factsheets/UK/FS_Naturalistic_driving_UK.pdf.

Jason Tester, BJ Fogg, and Michael Maile (2000). CommuterNews: A Prototype of Persuasive In-Car Entertainment. In: *CHI '00 Extended Abstracts on Human Factors in Computing Systems*. (CHI EA '00. The Hague, The Netherlands). ACM: New York, NY, USA, pp. 24–25. ISBN: 1-58113-248-4. DOI: 10.1145/633292.633309.

The Royal Society for the Prevention of Accidents (n.d.). *Seat Belts: A Short History*. URL: http://www.rospa.com/roadsafety/adviceandinformation/vehiclesafety/in-carsafetycrash-worthiness/seat-belt-history.aspx.

TomTom International BV (2009). *How TomTom's HD Traffic™ and IQ Routes™ Data Provides the Very Best Routing - Travel Time Measurements using GSM and GPS Probe Data*. Tech. rep. TomTom International BV. URL: https://www.tomtom.com/lib/doc/download/HDT_White_Paper.pdf.

Ingo Totzke, Nadja Rauch, Eric Ufer, Hans-Peter Krüger, and Siegfried Rothe (2008). Workload-Management im Verkehr: Prädiktion von

Fahrerbeanspruchung durch Informationen in digitalen Karten. German. In: *Fortschritte der Verkehrspsychologie*. Ed. by Jens Schade and Arnd Engeln. VS Verlag für Sozialwissenschaften, pp. 159–182. ISBN: 978-3-531-15956-0. DOI: 10.1007/978-3-531-90949-3_8.

Tammy E. Trimble, Richard Bishop, Justin F. Morgen, and Myra Blanco (2014). *Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts: Past Research, State of Automation Technology, and Emerging System Concepts*. Tech. rep. DOT HS 812 043. Washington, DC, USA: National Highway Traffic Safety Administration, July 2014.

Takayuki Tsuji, Hiroshi Hattori, Masahito Watanabe, and Nobuharu Nagaoka (2002). Development of Night-Vision System. In: *IEEE Transactions on Intelligent Transportation Systems* 3.3 (Sept. 2002), pp. 203–209. ISSN: 1524-9050. DOI: 10.1109/TITS.2002.802927.

Daniel Ullrich and Sarah Diefenbach (2010). INTUI. Exploring the Facets of Intuitive Interaction. In: *Mensch & Computer 2010: Interaktive Kulturen*. (Duisburg, Germany). Ed. by Jürgen Ziegler and Albrecht Schmidt. Oldenbourg Verlag: München, pp. 251–260. URL: http://dl.mensch-und-computer.de/handle/123456789/412.

A. R. A. van der Horst and Marieke H. Martens (2010). The Peripheral Detection Task (PDT): On-line Measurement of Driver Cognitive Workload and Selective Attention. In: *Performance Metrics for Assessing Driver Distraction: The Quest for Improved Road Safety*. Ed. by Gary L. Rupp. SAE International: Warrendale, PA, USA. Chap. 4, pp. 73–88. ISBN: 978-0-7680-3496-7.

Ingrid van Schagen, Ruth Welsh, Agatha BACKER-GRØNDAHL, Marika Hoedemaeker, Tsippy Lotan, Andrew Morris, Fridulv Sagberg, and Martin Winkelbauer (2011). *Towards a Large-Scale European Naturalistic Driving Study: Main Findings of PROLOGUE*. Tech. rep. PROLOGUE Deliverable D4.2. Leidschendam, The Netherlands: SWOV Institute for Road Safety Research.

W. van Winsum, Marieke H. Martens, and L. Herland (1999). *The Effects of Speech Versus Tactile Driver Support Messages on Workload, Driver Behaviour and User Acceptance*. Tech. rep. TNO report TM-99-C043. Soesterberg, The Netherlands: TNO Human Factors.

Trent W. Victor, Jonas Bärgman, Magnus Hjälmdahl, Katja Kircher, Erik Svanberg, Susanne Hurtig, Helena Gellerman, and Frederik Moeschlin (2010). *Sweden-Michigan Naturalistic Field Operational Test (SeMiFOT) Phase 1: Final Report*. Tech. rep. SAFER REPORT 2010:02. SAFER Vehicle and Traffic Safety Center at Chalmers. URL: http://www.chalmers.se/safer/EN/publications/traffic-safety-analysis/2010/sweden-michigan8650.

Trent W. Victor, Johan Engström, and Joanne L. Harbluk (2008). Distraction Assessment Methods Based on Visual Behavior and Event Detection. In: *Driver*

Distraction: Theory, Effects, and Mitigation. Ed. by Kristie Young, John D. Lee, and Michael A. Regan. CRC Press: Boca Raton, FL, USA. Chap. 10, pp. 135–165. ISBN: 9780849374265. DOI: 10.1201/9781420007497.ch10.

Roman Vilimek and Alf Zimmer (2007). Development and Evaluation of a Multimodal Touchpad for Advanced In-Vehicle Systems. English. In: *Engineering Psychology and Cognitive Ergonomics*. Ed. by Don Harris. Vol. 4562. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 842–851. ISBN: 978-3-540-73330-0. DOI: 10.1007/978-3-540-73331-7_92.

Pontus Wärnestål and Fredrik Kronlid (2014). Towards a User Experience Design Framework for Adaptive Spoken Dialogue in Automotive Contexts. In: *Proceedings of the 19th International Conference on Intelligent User Interfaces*. (IUI '14. Haifa, Israel). ACM: New York, NY, USA, pp. 305–310. ISBN: 978-1-4503-2184-6. DOI: 10.1145/2557500.2557506.

Timothy N. Welsh, Sanjay Chandrasekharan, Matthew Ray, Heather Neyedli, Romeo Chua, and Daniel J . Weeks (2012). Perceptual-Motor Interaction. In: *Human-Computer Interaction Handbook*. Ed. by Julie A. Jacko. Third Edition. CRC Press: Boca Raton, FL, USA. Chap. 1, pp. 3–20. ISBN: 978-1-4398-2943-1. DOI: doi:10.1201/b11963-3.

Mikael Wiberg and Steve Whittaker (2005). Managing Availability: Supporting Lightweight Negotiations to Handle Interruptions. In: *ACM Transactions Computuer-Human Interaction* 12.4 (Dec. 2005), pp. 356–387. ISSN: 1073-0516. DOI: 10.1145/1121112.1121114.

Christopher D. Wickens (2002). Multiple Resources and Performance Prediction. In: *Theoretical Issues in Ergonomics Science* 3.2, pp. 159–177. DOI: 10.1080/14639220210123806.

Christopher D. Wickens (2008). Multiple Resources and Mental Workload. In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50.3, pp. 449–455. DOI: 10.1518/001872008X288394.

Christopher D. Wickens and Pamela S. Tsang (2015). Workload. In: *APA handbook of human systems integration.* Ed. by Deborah A. Boehm-Davis, Francis T. Durso, and John D. Lee. APA handbooks in psychology. American Psychological Association: Washington, DC, USA. Chap. 18, pp. 277–292. DOI: 10.1037/14528-018.

Walter W. Wierwille (1993). Demands on Driver Resources Associated with Introducing Advanced Technology into the Vehicle. In: *Transportation Research Part C: Emerging Technologies* 1.2, pp. 133–142. ISSN: 0968-090X. DOI: 10.1016/0968-090X(93)90010-D.

Walter W. Wierwille, L. A. Ellsworth, S. S. Wreggit, R. J. Fairbanks, and C. L. Kirn (1994). *Research on Vehicle-based Driver Status/Performance Monitoring. Development, Validation, and Refinement of Algorithms For Detection of Driver*

Drowsiness. Final Report. Tech. rep. DOT HS 808 247. Washington, DC, USA: National Highway Transportation Safety Administration, Dec. 1994. URL: http://ntl.bts.gov/lib/jpodocs/repts_te/9006.pdf.

David Wilfinger, Alexander Meschtscherjakov, Martin Murer, Sebastian Osswald, and Manfred Tscheligi (2011). Are We There Yet? A Probing Study to Inform Design for the Rear Seat of Family Cars. English. In: *Human-Computer Interaction – INTERACT 2011*. Ed. by Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler. Vol. 6947. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 657–674. ISBN: 978-3-642-23770-6. DOI: 10.1007/978-3-642-23771-3_48.

David Wilfinger, Martin Murer, Axel Baumgartner, Christine Döttlinger, Alexander Meschtscherjakov, and Manfred Tscheligi (2013). The Car Data Toolkit: Smartphone Supported Automotive HCI Research. In: *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '13. Eindhoven, The Netherlands). ACM: New York, NY, USA, pp. 168–175. ISBN: 978-1-4503-2478-6. DOI: 10.1145/2516540.2516550.

Ute Winter, Tim J. Grost, and Omer Tsimhoni (2010). Language Pattern Analysis for Automotive Natural Language Speech Applications. In: *Proceedings of the 2Nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. (AutomotiveUI '10. Pittsburgh, PA, USA). ACM: New York, NY, USA, pp. 34–41. ISBN: 978-1-4503-0437-5. DOI: 10.1145/1969773.1969781.

Jacob O. Wobbrock, Meredith Ringel Morris, and Andrew D. Wilson (2009). User-Defined Gestures for Surface Computing. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. (CHI '09. Boston, MA, USA). ACM: New York, NY, USA, pp. 1083–1092. ISBN: 978-1-60558-246-7. DOI: 10.1145/1518701.1518866.

Hao-Yu Wu, Michael Rubinstein, Eugene Shih, John Guttag, Frédo Durand, and William Freeman (2012). Eulerian Video Magnification for Revealing Subtle Changes in the World. In: *ACM Trans. Graph.* 31.4 (July 2012), 65:1–65:8. ISSN: 0730-0301. DOI: 10.1145/2185520.2185561.

Robert M. Yerkes and John D. Dodson (1908). The Relation of Strength of Stimulus to Rapidity of Habit-Formation. In: *Journal of Comparative Neurology and Psychology* 18, pp. 459–482.

Kristie L. Young, Michael A. Regan, and Mike Hammer (2003). *Driver Distraction: A Review of the Literature*. Tech. rep. 206. Victoria, Australia: Monash University Accident Research Centre, Nov. 2003.

Kristie Young, John D. Lee, and Michael A. Regan (2008a). Defining Driver Distraction. In: *Driver Distraction: Theory, Effects, and Mitigation*. Ed. by

Kristie Young, John D. Lee, and Michael A. Regan. CRC Press: Boca Raton, FL, USA, 2008. Chap. 3, pp. 31–40. ISBN: 9780849374265. DOI: 10.1201/9781420007497.ch3.

Kristie Young, John D. Lee, and Michael A. Regan, eds. (2008b). *Driver Distraction : Theory, Effects, and Mitigation*. CRC Press: Boca Raton, FL, USA, 2008. ISBN: 978-0-8493-7426-5. DOI: 10.1201/9781420007497.

Richard A. Young, Li Hsieh, and Sean Seaman (2013). The Tactile Detection Response Task: Preliminary Validation for Measuring the Attentional Effects of Cognitive Load. In: *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. (DA '13. Bolton Landing, NY, USA), pp. 71–77. URL: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/012_Young_0.pdf.

A. Zeller, A. Wagner, and M. Spreng (2001). iDrive - Zentrale Bedienung im neuen 7er von BMW /iDrive - Centralised Operation in the new 7series of BMW. In: *Elektronik im Kraftfahrzeug. Tagung der VDI-Gesellschaft Fahrzeug- und Verkehrstechnik, Baden-Baden, 28. und 28. September 2001*. (Internationale Tagung Elektronik im Kraftfahrzeug. Baden-Baden, Germany). VDI-Berichte 1646 1646. VDI. Düsseldorf, Germany, Oct. 2001, pp. 997–1009.

Zhiwei Zhu, Kikuo Fujimura, and Qiang Ji (2002). Real-Time Eye Detection and Tracking Under Various Light Conditions. In: *Proceedings of the 2002 Symposium on Eye Tracking Research & Applications*. (ETRA '02. New Orleans, LA, USA). ACM: New York, NY, USA, pp. 139–144. ISBN: 1-58113-467-3. DOI: 10.1145/507072.507100.

Ferdinand Rudolf Hendrikus Zijlstra (1993). Efficiency in Work Behaviour: A Design Approach for Modern Tools. PhD thesis. Delft, The Netherlands: TU Delft, The Netherlands. ISBN: 90-6275-918-1.

Martin Zobl, Michael Geiger, Klaus Bengler, and Manfred Lang (2001). A Usability Study on Hand Gesture Controlled Operation of In-Car Devices. In: *Abridged Proceedings of 9th International Confence on Human Machine Interaction 2001*. (HCI International 2001. New Orleans, LA, USA). Lawrence Erlbaum Ass.: New Jersey, USA, pp. 263–267.

Martin Zobl, Michael Geiger, Björn Schuller, Manfred Lang, and Gerhard Rigoll (2003). A Real-Time System for Hand Gesture Controlled Operation of In-Car Devices. In: *Proceedings of the International Conference on Multimedia and Expo 2003*. (ICME '03). Vol. 3. July 2003, pp. III-541–III-544. ISBN: 0-7803-7965-9. DOI: 10.1109/ICME.2003.1221368.

VII

APPENDIX

Appendix A

Communication Preferences Survey

Telekommunikation beim Autofahren

In dieser Umfrage untersuchen wir die Nutzerpräferenzen bei Telefonaten mit Personen, die während des Telefonats Auto fahren.

Herzlich Willkommen und vielen Dank, dass Sie sich die Zeit nehmen, an dieser Umfrage teilzunehmen. Die Umfrage dauert etwa **15 Minuten**. Sie können die Umfrage jederzeit unterbrechen und später wieder fortsetzen. Bitte beachten Sie dazu die entsprechenden Hinweise.

Die Ergebnisse dieser Umfrage sollen helfen, in Zukunft Telekommunikation beim Autofahren angenehmer und sicherer zu gestalten. Unsere Fragen beziehen sich daher auf Ihr derzeitiges Telekommunikationsverhalten, wenn Sie selbst fahren bzw. mit einem Autofahrer kommunizieren.

Das Ausfüllen des Fragebogens ist freiwillig. Die Auswertung erfolgt selbstverständlich *anonym* und unter Einhaltung des Datenschutzes.

Gerne können Sie die Internetadresse zu dieser Umfrage an Freunde und Bekannte weiterleiten. Dazu können Sie z.B. die Buttons unten verwenden.

Herzlichen Dank für Ihre Unterstützung!

Bei Rückfragen können Sie sich jederzeit an uns wenden. Die Umfrage wird durchgeführt von:

Universität Stuttgart
Institut für Visualisierung und Interaktive Systeme
Abteilung Mensch-Computer-Interaktion
Dipl.-Inf. Bastian Pfleging
Pfaffenwaldring 5a
70569 Stuttgart

E-Mail
http://www.vis.uni-stuttgart.de/institut/abteilungen/mci.html

Impressum

Diese Umfrage enthält 41 Fragen.

Führerschein und Auto

Welche Antworten treffen bei Ihnen bzgl. der Nutzung von Autos zu?

1 Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein

2 Seit wann sind Sie im Besitz einer gültigen Fahrerlaubnis?

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte ein Datum eingeben:

[ ]

Wann haben Sie Ihren ersten regulären Führerschein bestanden?

3 Wie häufig fahren Sie selbst Auto? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Regelmäßig (fast täglich)
- ○ Öfters (2-3 mal pro Woche)
- ○ Ab und zu (1 mal pro Woche)
- ○ Selten (weniger als 1 mal pro Woche)
- ○ Nie

4 Besitzen Sie ein eigenes Auto bzw. haben Zugriff auf ein Ihnen überlassenes Auto? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja, ein eigenes Auto
- ○ Ja, ein mir permanent überlassenes Auto
- ○ Ja, ein mir zeitweise überlassenes Auto
- ○ Nein
- ○ Keine Angabe

5 Besitzt das von Ihnen genutzte Auto eine Freisprecheinrichtung? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?) *und* Antwort war NICHT 'Nein' bei Frage '4 [CarAccess]' (Besitzen Sie ein eigenes Auto bzw. haben Zugriff auf ein Ihnen überlassenes Auto?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja, eine integrierte Freispreicheinrichtung
- ○ Ja, über ein nachträglich eingebautes, mobiles Navigationssystem
- ○ Nein, ich nutze aber ein Headset
- ○ Nein, ich nutze aber die Laut-Hören-Funktion meines Telefons
- ○ Nein
- ○ Sonstiges [ ]

Nutzung von Mobiltelefonen

Zu Beginn möchten wir einige allgemeine Informationen zur Nutzung von Mobiltelefonen erfragen.

6 Besitzen Sie ein Mobiltelefon oder Smartphone? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja, ein Smartphone
- ○ Ja, ein herkömmliches Mobiltelefon / Handy
- ○ Nein

7 Nutzen Sie über Ihren Mobilfunkanbieter eine mobile Datenverbindung (UMTS, 3G, 4G) auf Ihrem Handy, um im Internet zu surfen oder sonstige Internet-Dienste zu verwenden? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '6 [PhoneOwner]' (Besitzen Sie ein Mobiltelefon oder Smartphone?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein

8 Beinhaltet der von Ihnen gebuchte Mobilfunktarif eine "Datenflatrate"? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '6 [PhoneOwner]' (Besitzen Sie ein Mobiltelefon oder Smartphone?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein
- ○ Keine Ahnung

9 Welche Kommunikationsdienste Ihres Mobiltelefons nutzen Sie generell?

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '6 [PhoneOwner]' (Besitzen Sie ein Mobiltelefon oder Smartphone?)

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Telefonieren
- ☐ SMS
- ☐ MMS
- ☐ E-Mail
- ☐ Übrige Kurznachrichten (z.B. Whats App, ICQ, ...)
- ☐ Skype
- ☐ Internet-Surfen
- ☐ SIP-Telefonie (Internet-Telefonie)
- ☐ Sonstiges: ____________

Derzeitige Telekommunikation im Auto

Wie kommunizieren derzeit im Auto?

10 Wie häufig telefonieren Sie im Auto, wenn Sie selbst fahren (unabhängig, ob mit oder ohne Freisprecheinrichtung)? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Regelmäßig (fast täglich)
- ○ Öfters (2-3 mal pro Woche)
- ○ Ab und zu (1 mal pro Woche)
- ○ Selten (weniger als 1 mal pro Woche)
- ○ Nie

11 Wie beeinflusst Sie das Telefonieren beim Autofahren? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?) *und* Antwort war NICHT 'Nie' bei Frage '10 [CallDriving]' (Wie häufig telefonieren Sie im Auto, wenn Sie selbst fahren (unabhängig, ob mit oder ohne Freisprecheinrichtung)?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Stark unterstützend (1)
- ○ Unterstützend (2)
- ○ Leicht unterstützend (3)
- ○ Kein Einfluss (4)
- ○ leicht ablenkend (5)
- ○ Ablenkend (6)
- ○ Stark ablenkend (7)
- ○ Keine Aussage

12 Lesen Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Kurznachrichten (SMS, WhatsApp, etc.)
- ☐ E-Mails
- ☐ Ja, während des Fahrens
- ☐ Nein, ich versuche zunächst, anzuhalten
- ☐ Nein, nur wenn ich angehalten habe
- ☐ Nein, erst wenn ich am Ziel angekommen bin
- ☐ Sonstiges: ________

13 Wie beeinflusst Sie das Lesen von Mitteilungen beim Autofahren? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?) *und* Antwort war 'E-Mails' *oder* 'Kurznachrichten (SMS, WhatsApp, etc.)' bei Frage '12 [ReadingDriving]' (Lesen Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen?) *und* Antwort war 'E-Mails' *oder* 'Kurznachrichten (SMS, WhatsApp, etc.)' bei Frage '12 [ReadingDriving]' (Lesen Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Stark unterstützend (1)
- ○ Unterstützend (2)
- ○ Leicht unterstützend (3)
- ○ Kein Einfluss (4)
- ○ Leicht ablenkend (5)
- ○ Ablenkend (6)
- ○ Stark ablenkend (7)
- ○ Keine Aussage

14 Schreiben Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Kurznachrichten (SMS, WhatsApp, etc.)
- ☐ E-Mails
- ☐ Ja, während des Fahrens
- ☐ Nein, ich versuche zunächst, anzuhalten
- ☐ Nein, nur wenn ich angehalten habe
- ☐ Nein, erst wenn ich am Ziel angekommen bin
- ☐ Sonstiges: ________

15 Wie beeinflusst Sie das Schreiben von Mitteilungen beim Autofahren? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?) *und* Antwort war 'E-Mails' *oder* 'Kurznachrichten (SMS, WhatsApp, etc.)' bei Frage '14 [WritingDriving]' (Schreiben Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen?) *und* Antwort war 'E-Mails' *oder* 'Kurznachrichten (SMS, WhatsApp, etc.)' bei Frage '14 [WritingDriving]' (Schreiben Sie Mitteilungen auf Ihrem Handy, wenn Sie selbst fahren? In welchen Situationen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Stark unterstützend (1)
- ○ Unterstützend (2)
- ○ Leicht unterstützend (3)
- ○ Kein Einfluss (4)
- ○ Leicht ablenkend (5)
- ○ Ablenkend (6)
- ○ Stark ablenkend (7)
- ○ Keine Aussage

LimeSurvey - Telekommunikation beim Autofahren http://surveys.hcilab.org/index.php/admin/printablesurvey/sa/ind...

Kontextinformationen beim Autofahren

Stellen Sie sich bei den folgenden Fragen vor, dass Sie im Auto unterwegs sind und selbst das Fahrzeug steuern.

Stellen Sie sich außerdem vor, dass Ihr Auto gewisse Informationen über die aktuelle Situation mit Ihren Anrufern bzw. Kommunikationspartnern außerhalb des Autos teilen kann.

16 Welche Informationen über Ihre aktuelle Fahrsituation würden Sie als Fahrer(in) bei jedem Anruf automatisch für die einzelnen Personengruppen preisgeben wollen?
Bitte treffen Sie für jede der Personengruppen Ihre Auswahl (Mehrfachauswahl ist pro Gruppe und Information möglich)! *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

	Exakter aktueller Aufenthaltsort	Aktuelle(r) Stadt / Stadtteil	Video der aktuellen Fahrsituation	Standbild der aktuellen Fahrsituation	Aktuelles Video, das den Fahrer zeigt	Aktuelles Standbild, das den Fahrer zeigt	Derzeitige Verkehrssituation (Symbol / Text)	Aktueller Straßentyp	Wetter	Aktuelle Geschwindigkeit	Aktueller Stresspegel, z.B. „angespannt“ / „entspannt“	ke Infor
engste Famile (Partner(in), Kinder, Eltern)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
übrige Familie	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
gute Freunde	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Bekannte	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Arbeitskollegen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Sonstige Anrufer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

17 Welche Informationen über Ihre aktuelle Fahrtroute würden Sie als Fahrer(in) bei jedem Anruf automatisch für die einzelnen Personengruppen preisgeben wollen?
Bitte treffen Sie für jede der Personengruppen Ihre Auswahl (Mehrfachauswahl ist pro Gruppe und Information möglich)! *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
((DrivingLicense.NAOK != "N"))

	Ziel der aktuellen Fahrt	Zeit bis zur Ankunft am Ziel	Vergangene Zeit seit der Abfahrt am Start	Anzahl der Mitfahrer im Auto	keine Information
engste Famile (Partner(in), Kinder, Eltern)	☐	☐	☐	☐	☐
übrige Familie	☐	☐	☐	☐	☐
gute Freunde	☐	☐	☐	☐	☐
Bekannte	☐	☐	☐	☐	☐
Arbeitskollegen	☐	☐	☐	☐	☐
Sonstige Anrufer	☐	☐	☐	☐	☐

18 Welche Informationen über Ihre Fahrsituation würden Sie als Fahrer(in) beim Telefonieren gezielt (z.B. abhängig vom Anrufer und der Situation), aber manuell preisgeben wollen? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Exakter aktueller Aufenthaltsort
- ☐ Aktuelle(r) Stadt / Stadtteil
- ☐ Video der aktuellen Fahrsituation
- ☐ Standbild der aktuellen Fahrsituation
- ☐ Aktuelles Video, das den Fahrer zeigt
- ☐ Aktuelles Standbild, das den Fahrer zeigt
- ☐ Derzeitige Verkehrssituation (Symbol / Text)
- ☐ Aktueller Straßentyp
- ☐ Wetter
- ☐ Aktuelle Geschwindigkeit
- ☐ Ziel der aktuellen Fahrt
- ☐ Zeit bis zur Ankunft am Ziel
- ☐ Vergangene Zeit seit der Abfahrt am Start
- ☐ Anzahl der Mitfahrer im Auto
- ☐ Aktueller Stresspegel, z.B. „angespannt“ / „entspannt“
- ☐ keine Information

19 Welchen Einfluss auf die Kommunikation würden Sie durch das Teilen der Informationen erwarten?

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte geben Sie Ihre Antwort hier ein:

20 Wären Sie einverstanden, wenn Ihr Anruf automatisch unterbrochen wird, sofern es die Verkehrslage so erfordert (z.B. viel befahrene Kreuzung, Stauende)? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja, die angerufene Person bekommt dabei eine Information, warum der Anruf gerade unterbrochen wird (z.B. viel Verkehr, schlechte Sicht, ...)
- ○ Ja, die angerufene Person hört dabei nur eine allgemeine Wartemelodie/-mitteilung
- ○ Ja, das Telefonat kann abgebrochen/beendet und später fortgesetzt werden
- ○ Nur, wenn ich selbst bestimmen kann, wann unterbrochen wird
- ○ Nein
- ○ Sonstiges ____________

Videoübertragung aus dem Auto

Nehmen Sie an, Sie fahren ein Auto und dieses Auto kann Ihrem Gesprächspartner (wie einem Beifahrer) beim Telefonieren Bilder der derzeitigen Verkehrssituation übermitteln.

21 Denken Sie, dass die Übertragung von Bildern (z.B. wie unten dargestellt) Ihre Privatsphäre als Fahrer(in) beeinflussen?

*

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein

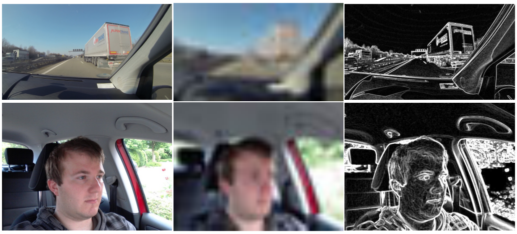
22 Wie oft würden Sie als Fahrer(in) beim Fahren Bilder übermitteln lassen? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Live-Video mit Bewegtbildern
- ○ Alle 10 Sekunden ein Standbild
- ○ Nur ein Standbild beim Aufbau der Verbindung
- ○ Kein Bild

23 Für die Übertragung des Videos aus Ihrem Auto während Ihrer Fahrt sind verschiedene Darstellungen möglich, die z.B. unterschiedliche Details umfassen könnten und damit auch Ihren Bedarf nach Privatsphäre unterschiedlich unterstützen. Wie sollen die übermittelten Bilder aussehen bzw. wie geeignet finden Sie die einzelnen Darstellungen?



Farbbild (hohe Auflösung) **Farbbild (niedrige Auflösung)** **Kantenbild**

*

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie mindestens eine Antwort.

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

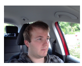
	sehr geeignet 1	2	3	4	5	6	sehr ungeeignet 7
Farbbild (hohe Auflösung)	○	○	○	○	○	○	○
Farbbild (niedrige Auflösung)	○	○	○	○	○	○	○
Kantenbild	○	○	○	○	○	○	○

24 Welche Ansicht würden Sie als Fahrer(in) am liebsten teilen wollen?

Blick nach vorne

Blick durch Seitenscheibe

Rundumblick



Blick auf Fahrer

*

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Blick nach vorne (auf die Straße)
- ○ Blick durch Seitenscheibe
- ○ Rundumblick
- ○ Blick auf Fahrer

25 Würden Sie es begrüßen, bei jedem Anruf die Art der zu übertragenden Video-Ansicht (wie in der Frage zuvor) wählen zu können? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte wählen Sie nur eine der folgenden Antworten aus:

○ Ja
○ Nein

26 Angenommen, Sie als Fahrer(in) übermitteln beim Anruf ein Bild/Video an Ihre(n) Gesprächspartner(in): würden Sie erwarten, dass die Person auf die dadurch übermittelten Informationen / die Verkehrssituation eingeht? Wie könnte dies aussehen?

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '1 [DrivingLicense]' (Besitzen Sie einen Führerschein, mit dem Sie normale Autos / PKWs fahren dürfen?)

Bitte geben Sie Ihre Antwort hier ein:

Kommunikation mit Autofahrern

Stellen Sie sich bei den folgenden Fragen vor, dass Sie mit einer Person kommunizieren, die im Auto unterwegs ist und das Fahrzeug steuert. **Sie selbst sind dabei nicht im Auto unterwegs.**

Stellen Sie sich zudem vor, die anzurufende Person teilt einige Situationsinformationen mit Ihnen.

27 Wenn Sie eine Person auf dem Handy anrufen, wäre es dann für Sie interessant, zu wissen, ob die Person im Auto unterwegs ist? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein

28 Welche Statusinformationen würden Sie beim Telefonieren <u>mit einer Person, die gerade ein Auto fährt</u>, interessieren? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nein' bei Frage '27 [CallerDrivingInfo]' (Wenn Sie eine Person auf dem Handy anrufen, wäre es dann für Sie interessant, zu wissen, ob die Person im Auto unterwegs ist?)

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Exakter aktueller Aufenthaltsort
- ☐ Aktuelle(r) Stadt / Stadtteil
- ☐ Video der aktuellen Fahrsituation
- ☐ Standbild der aktuellen Fahrsituation
- ☐ Aktuelles Video, das den Fahrer zeigt
- ☐ Aktuelles Standbild, das den Fahrer zeigt
- ☐ Derzeitige Verkehrssituation (Symbol / Text)
- ☐ Aktueller Straßentyp
- ☐ Wetter
- ☐ Aktuelle Geschwindigkeit
- ☐ Ziel der aktuellen Fahrt
- ☐ Zeit bis zur Ankunft am Ziel
- ☐ Vergangene Zeit seit der Abfahrt am Start
- ☐ Anzahl der Mitfahrer im Auto
- ☐ Aktueller Stresspegel, z.B. „angespannt" / „entspannt"
- ☐ keine Information
- ☐ Sonstiges: ____________

**29 Nehmen Sie nun an, die anzurufende Person teilt einige der zuvor aufgeführten Situationsinformationen mit Ihnen.
Auf welche Art würden Sie am liebsten diese Informationen erhalten? ***

Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ Text
- ☐ Symbol
- ☐ Bild
- ☐ Video
- ☐ Gesprochener Hinweis
- ☐ Symbol + Text
- ☐ Bild + Text
- ☐ Video + Text
- ☐ Gesprochener Hinweis + Text und/oder Symbol
- ☐ Keine
- ☐ Sonstiges: ____________

30 Wann würden Sie am liebsten diese Informationen erhalten? *Bewerten Sie bitte, wie hilfreich die Informationen zu den dargestellten Zeitpunkten wären.* *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	hilfreich 1	2	3	4	5	6	nicht hilfreich 7
Bei der Eingabe der Rufnummer (d.h., beim Tippen der Nummer bzw. bei der Auswahl im Adressbuch)	○	○	○	○	○	○	○
Vor dem Verbindungsaufbau: Ich bekomme die Information und muss dann entscheiden, wirklich anrufen zu wollen	○	○	○	○	○	○	○
Vor dem Verbindungsaufbau: Ich bekomme die Information und es wird nach 5 Sekunden gewählt, wenn ich bis dahin nicht auflege	○	○	○	○	○	○	○
Beim Verbindungsaufbau: Es klingelt bereits, während die Information gegeben wird	○	○	○	○	○	○	○
Sobald die Verbindung steht: Wenn der Fahrer abhebt, erhalte ich die Information	○	○	○	○	○	○	○
Kontinuierlich während des Telefonats	○	○	○	○	○	○	○

31 Sie telefonieren bzw. wollen mit einer Person telefonieren, die gerade ein Auto fährt. Wie würden Sie in den folgenden Situationen Ihr Gesprächsverhalten anpassen, wenn Sie z.B. durch Live-Video, Text oder Symbol von der aktuellen Situation erfahren? *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	Nicht anrufen bzw. wieder auflegen	Auflegen und Nachricht schreiben	Erneut anrufen wenn die Situation vorbei ist	Anrufen, wenn der Fahrer am Ziel angekommen ist	Normal anrufen / weiter telefonieren	Anrufen / weiter telefonieren, aber mich kurz fassen	Warten, bis die Situation vorbei ist
"Langweilige" Situation, z.B. wenig Verkehr / bekannter Strecke / freie Autobahn / schönes Wetter	○	○	○	○	○	○	○
"Normale" Situation, z.B. mittlerer Verkehr / Stadtverkehr / leeres Autobahnkreuz	○	○	○	○	○	○	○
"Anspruchsvolle" Situation, z.B. viel (Stadt-)Verkehr / hohe Geschwindigkeit / unbekannte bzw. unübersichtliche Strecke / schlechtes Wetter	○	○	○	○	○	○	○

32 Sie sind mit einer Person per Kurznachricht im Kontakt, die gerade ein Auto fährt. Wie würden Sie in den folgenden Situationen Ihr Gesprächsverhalten anpassen, wenn Sie z.B. durch Live-Video, Text oder Symbol von der aktuellen Situation erfahren? *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	Keine Nachricht schicken	Nachricht schicken, wenn die Situation vorbei ist	Nachricht schicken, wenn der Fahrer am Ziel angekommen ist	Normal Nachrichten schicken	Normal Nachrichten schicken, aber mich kurz fassen
"Langweilige" Situation, z.B. wenig Verkehr / bekannter Strecke / freie Autobahn / schönes Wetter	○	○	○	○	○
"Normale" Situation, z.B. mittlerer Verkehr / Stadtverkehr / leeres Autobahnkreuz	○	○	○	○	○
"Anspruchsvolle" Situation, z.B. viel (Stadt-)Verkehr / hohe Geschwindigkeit / unbekannte bzw. unübersichtliche Strecke / schlechtes Wetter	○	○	○	○	○

33 Wären Sie einverstanden, wenn Ihr Anruf automatisch unterbrochen wird, sofern es die Verkehrslage so erfordert (z.B. viel befahrene Kreuzung, Stauende)? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja, wenn ich eine Information erhalte, warum der Anruf gerade unterbrochen wird (z.B. viel Verkehr, schlechte Sicht, ...)
- ○ Ja, wenn ich eine allgemeine Wartemelodie/-mitteilung höre
- ○ Ja, das Telefonat kann abgebrochen/beendet und später fortgesetzt werden
- ○ Nur, wenn ich selbst bestimmen kann, wann unterbrochen wird
- ○ Nein
- ○ Sonstiges ____

Videoübertragung zum Anrufer

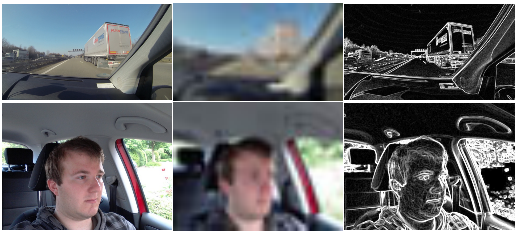
Nehmen Sie an, dass Sie sich per Telefon mit einer Person unterhalten, die gerade Auto fährt. Stellen Sie sich zudem vor, dass das Fahrzeug der angerufenen Person die Möglichkeit bietet, Ihnen beim Telefonieren Bilder der derzeitigen Verkehrssituation (wie einem Beifahrer) zu übermitteln.

34 Wie oft würden Sie diese Bilder <u>als Anrufer außerhalb des Autos</u> sehen wollen? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Live-Video mit Bewegtbildern
- ○ Alle 10 Sekunden ein Standbild
- ○ Nur ein Standbild beim Aufbau der Verbindung
- ○ Kein Bild

35 Für die Übertragung des Videos sind verschiedene Darstellungen möglich, die z.B. unterschiedliche Details umfassen könnten und damit auch den Bedarf des Fahrers nach Privatsphäre unterschiedlich unterstützen. Wie soll das übermittelte Bild aussehen bzw. wie geeignet finden Sie <u>als Anrufer außerhalb des Autos</u> die einzelnen Darstellungen?



Farbbild (hohe Auflösung) **Farbbild (niedrige Auflösung)** **Kantenbild**

*

Bitte wählen Sie mindestens eine Antwort.

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

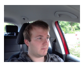
	sehr geeignet 1	2	3	4	5	6	sehr ungeeignet 7
Farbbild (hohe Auflösung)	○	○	○	○	○	○	○
Farbbild (niedrige Auflösung)	○	○	○	○	○	○	○
Kantenbild	○	○	○	○	○	○	○

36 Welche Ansicht würden Sie <u>als Anrufer außerhalb des Autos</u> am liebsten sehen wollen?

Blick nach vorne

Blick durch Seitenscheibe

Rundumblick



Blick auf Fahrer

*

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Blick nach vorne auf die Straße
- ○ Blick durch die Seitenscheibe
- ○ Rundumblick
- ○ Blick auf den Fahrer

Allgemeine Angaben

Zum Abschluss würden wir gerne noch einige allgemeine Informationen erfragen:

37 Bitte nennen Sie uns Ihr Geschlecht:

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ weiblich
- ○ männlich

38 Wie alt sind Sie?

Jede Antwort muss zwischen 10 und 99 sein

Bitte geben Sie Ihre Antwort hier ein:

39 Welches ist Ihr höchster Bildungsabschluss?

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Schulabschluss
- ○ Abgeschlossene Ausbildung
- ○ Hochschulabschluss
- ○ Sonstiges

40 Sind Sie derzeit Student(in)?

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Ja
- ○ Nein

41 Haben Sie noch weitere Fragen oder Anmerkungen zu dieser Umfrage oder zu Ihren Antworten?

Bitte geben Sie Ihre Antwort hier ein:

Vielen Dank für Ihre Teilnahme!

Wenn Sie noch Rückfragen zur Umfrage haben, über Ergebnisse oder weitergehende Studien informiert werden möchten, schreiben Sie uns eine E-Mail an bastian.pfleging@vis.uni-stuttgart.de.

Ihre E-Mail-Adresse werden wir dann selbstverständlich unabhängig von Ihren Antworten der Umfrage speichern, so dass kein Rückschluss auf Ihre Antworten möglich ist.

Mit dem Senden der E-Mail erklären Sie sich einverstanden, dass wir Sie auf diesem Weg kontaktieren dürfen.

28.05.2013 – 00:00

Übermittlung Ihres ausgefüllten Fragebogens:
Vielen Dank für die Beantwortung des Fragebogens.

Bastian Pfleging

Automotive User Interfaces for the Support of Non-Driving-Related Activities

Driving a car has changed a lot since the first car was invented. Today, drivers do not only maneuver the car to their destination but also perform a multitude of additional activities in the car. This includes for instance activities related to assistive functions that are meant to increase driving safety and reduce the driver's workload. However, since drivers spend a considerable amount of time in the car, they often want to perform non-driving-related activities as well. In particular, these activities are related to entertainment, communication, and productivity. The driver's need for such activities has vastly increased, particularly due to the success of smart phones and other mobile devices. As long as the driver is in charge of performing the actual driving task, such activities can distract the driver and may result in severe accidents. Due to these special requirements of the driving environment, the driver ideally performs such activities by using appropriately designed in-vehicle systems. The challenge for such systems is to enable flexible and easily usable non-driving-related activities while maintaining and increasing driving safety at the same time.

The main contribution of this thesis is a set of guidelines and exemplary concepts for automotive user interfaces that offer safe, diverse, and easy-to-use means to perform non-driving-related activities besides the regular driving tasks. Using empirical methods that are commonly used in human-computer interaction, we investigate various aspects of automotive user interfaces with the goal to support the design and development of future interfaces that facilitate non-driving-related activities. The first aspect is related to using physiological data in order to infer information about the driver's workload. As a second aspect, we propose a multimodal interaction style to facilitate the interaction with multiple activities in the car. In addition, we introduce two concepts for the support of commonly used and demanded non-driving-related activities: For communication with the outside world, we investigate the driver's needs with regard to sharing ride details with remote persons in order to increase driving safety. Finally, we present a concept of time-adjusted activities (e.g., entertainment and productivity) which enable the driver to make use of times where only little attention is required. Starting with manual, non-automated driving, we also consider the rise of automated driving modes.